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WALNUT
Insects and Diseases

Workshop Proceedings
June 13-14, 1978
Carbondale, Illinois

North Central Forest Experiment Station, Forest Service, U.S. Department of Agriculture

PREFACE

Black walnut wood commands premium prices and so tree farmers and foresters plant thousands of acres each year to black walnut. With this increased emphasis on growing more walnut for wood production comes an increased concern for the role that insects and diseases may have in hindering that goal.

In 1973 Congress allocated the first monies for research on the insect and disease problems of black walnut. The money was distributed among researchers at several Universities in the form of cooperative-aid agreements because the Forest Service had no permanent personnel assigned to this area of research. However, in 1975 the Forest Service added a full-time entomologist and in 1977 a full-time pathologist to its multifunctional research team at Carbondale, Illinois, studying black walnut.

A great deal has been learned in the 5 years since federally supported research on black walnut pests began. Necessarily, researchers gave early emphasis to identifying or dismissing specific insects and diseases as serious threats to tree survival, growth, and reproduction.

The papers and discussions presented here summarize results of up to 5 years of recent study on insect and disease problems of black walnut and its close relative, butternut. These papers were given at a workshop held in Carbondale, Illinois, June 13 and 14, 1978, and sponsored by the USDA Forest Service, North Central Forest Experiment Station. The workshop featured state-of-the-art information and technical data presented by former and current researchers on the pests of black walnut. Except for those prepared by North Central Station researchers, the papers are reproduced here as they were received from the authors.

This information will be particularly useful to researchers and planning groups in designing new studies and determining the future direction of black walnut protection research.

(Mention of trade names does not constitute endorsement by the U.S. Department of Agriculture, Forest Service.)

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PREMATURE LOSS OF DEVELOPING BLACK WALNUT FRUIT

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ABSTRACT.--Good seed crops of black walnut are produced irregularly and the demand for nuts often exceeds the supply. The development of fruit clusters from 7 trees was followed from 1975 to 1977 to find out whether significant losses were occurring during development, and, if so, what was causing it. Results showed that 40 to 60 percent of the fruit is lost in the period following flowering. Control pollinations indicated that this post-bloom abortion may be due to natural pollination failures and that yield could be increased more than 250 percent if it could be prevented.

Good seed crops of black walnut (Juglans nigra L.) are produced irregularly. During average or poor seed crop years, demand for seed by nurseries and other users may exceed its availability. Some evidence suggests that diseases such as walnut anthracnose (Crane 1948) and insects such as the walnut curculio (Brooks 1922) contribute to the scarcity of walnut seed. In this study, fruit from 7 black walnut trees were inspected from 1975 to 1977 to determine if seed was lost during development and, if so, what was causing the seed to abort.

MATERIALS AND METHODS

Study trees were located in a formerly pastured area near Dodgeville, Wisconsin. In the spring at the time of first appearance of the female flowers, fruit clusters were numbered and tagged so their locations could be found again even if the fruit aborted. Clusters throughout the crowns up to a height of about 40 feet were accessible by using a truck-mounted ladder. At 1- to 4-week intervals, depending on the stage of development, the fruit were inspected, measured, recorded whether absent or present and noted for quality. In early fall all fruit on the study trees was harvested and counted.

RESULTS

1975

On June 17, 152 fruit were tagged. Of these fruit 11 percent aborted due to curculio infestation and 30 percent aborted during development from unknown causes (Table 1).

Table 1.--Black walnut fruit, Dodgeville, Wisconsin, 1975 and 1976

Growth period	Fruit at beginning of period	Fruit lost	
	Number	*Number*	*Percent*
1975			
June 17-July 15	152	42	27
July 16-August 26	110	10	7
August 27-September 15	100	10	7
Yield	90 (59 percent)		
1976			
Post bloom	304	187	62
Early expansion	117	32	11
Late expansion and maturation	85	3	1
Yield	82 (27 percent)		

1976

On May 25, when first recognizable, 304 fruit were tagged. More than 60 percent of these fruit aborted shortly after flowering and another 8 percent were lost due to curculio infestation (Table 1). The early season fruit abortion per tree ranged from 42 to 100 percent (Table 2).

Table 2.--Early season walnut fruit abortion at Dodgeville, Wisconsin, 1976

Tree	Inspected	Aborted by June 15	
	Number	*Number*	*Percent*
1	38	16	42
2	47	26	55
3	34	15	44
4	41	41	100
5	41	34	83
6	42	19	45
7	61	36	59
Total	304	187	62

After the postbloom abortion period, 34 fruit became weeviled and 23 of these dropped--an 8 percent fruit loss. As shown below, late season fruit retention was high:

Tree	Fruit present July 13	Fruit present August 25
1	8	7
2	20	20
3	15	14
4	0	0
5	6	6
6	16	15
7	20	20
Total	85	82 **(99%)**

The end-of-the-season fruit counts were used to derive estimates of potential yield if no early season abortion occurred. They reveal, as shown below, that the 1976 seed crop would have been more than 2½ times larger without early season abortion:

Tree	Actual seed present September 10	Potential seed if no early abortion
1	23	40
2	234	520
3	54	96
4	0	41
5	70	412
6	37	67
7	722	1,761
Total	1,140	2,937

1977

On May 24, 363 fruit were tagged. By examining fruit abscission scars of doublet, triplet, and quadruplet fruit clusters, it was determined that 11 percent of the fruit had already aborted (Table 3). By June 2, 30 percent had aborted and by June 14 another 10 percent had aborted. An analysis of abortion losses of triplet, doublet, and singlet clusters indicated that losses were in the order triplet > doublet > singlet (Table 4).

Table 3.--Early season walnut fruit abortion at Dodgeville, Wisconsin, 1977

(In numbers)

Tree	Inspected	Aborted by May 24	Aborted by June 2	Aborted by June 14
1	19	0	2	3
9	44	7	14	15
18	42	14	18	21
22	46	0	7	18
A	68	0	12	16
B	53	0	15	15
C	41	4	23	34
D	50	15	17	22
Total	363	40 (11%)	108 (30%)	144 (40%)

DISCUSSION

The cause of the early season abortion is not known. Fruit clusters enclosed in cheesecloth bags for 1 week became brown, shriveled, and aborted, and dissection of the fruit did not reveal evidence of insect injury. Stigmal feeding by insects was noted on several flowers but was so infrequent that it could not account for the extensive early abortion.

Imperfect pollination was investigated to a limited extent by comparing the abortion rate of hand pollinated clusters with naturally pollinated ones. Fourteen percent of hand-pollinated flowers aborted and 37 percent of naturally pollinated flowers aborted, which indicates that lack of pollination may be a cause of postbloom abortion and should be investigated further.

Table 4.--Early season abortion of walnut triplet, doublet, and singlet fruit clusters, 1977

Cluster	Present May 24	Present June 14				Remaining on June 14
		Triplet	Doublet	Singlet	Completely aborted	
	Number					*Percent*
Triplet	66	14	25	16	11	55
Doublet	66	--	33	18	15	64
Singlet	16	--	--	12	4	75

Table 5.--Walnut fruit loss during middle development period at Dodgeville, Wisconsin, 1976

Tree	Present June 15	Weeviled by June 15	Weeviled by July 13	Lost between June 15 and July 13-- cause unknown	Present July 13
1	22 (58%)[1]	14	11	3	8
2	21 (45%)	0	0	1	20
3	19 (56%)	1	1	3	15
4	0 (0%)	0	0	0	0
5	7 (17%)	0	0	1	6
6	23 (55%)	10	7	0	16
7	25 (41%)	9	4	1	20
Total	117 (38%)	34 (11%)	23 (8%)	9 (3%)	85 (28%)

[1]Percent of fruit present in spring at first examination on May 25.

Newly formed fruit are fragile and are vulnerable to dislodgment by wind and leaf action. Although some dislodgment by this means undoubtedly takes place, it does not seem likely that it is responsible for the complete loss of a tree's fruit (Table 5).

An interesting although minor cause of fruit loss was noticed in 1978. When red-winged blackbirds perched at the tops of terminal leaf clusters containing fruit, they sometimes knocked the smaller fruit loose, particularly when they landed and took off.

The walnut curculio was an important cause of fruit loss. However, not all fruit that contained oviposition scars aborted. For example, in 1976, 11 percent of the fruit bore oviposition scars but only 8 percent actually aborted (Table 6). The scars on the fruit that did not abort were confined to the outer husks.

Although anthracnose and bacterial blight lesions disfigured fruit husks, they seemed to have little affect on seed abortion. The same was true for husk fly infestation, which came late in the season after the fruit had attained their final size. Occasionally, the rot associated with a husk fly infestation spread to where the fruit was attached to the branch and caused the fruit to drop prematurely.

Table 6.--The effect of hand pollination on incidence of postbloom abortion

Tree	Hand-pollinated flowers		Naturally pollinated flowers	
	Retained	Aborted	Retained	Aborted
1	8	3	3	3
2	29	3	21	11
3	23	4	20	10
4	28	4	18	12
Total	88	14 (14%)	62	36 (37%)

CONCLUSION

The yield of walnut seed would be more than doubled if no early season abortion occurred. All the causes for abortion are not known but some of the major ones are lack of pollination and attack by curculio. If some of these causes could be overcome, the yield of walnut seed could be greatly increased.

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GROUP DISCUSSION

Kuntz: How much do we know about the insect and disease problems of butternut seed?

Kessler: Butternut has similar, and in some cases, identical seed insect and disease problems to black walnut. In the wild state cross-pollination of butternut is probably not as effective as it might be because of the irregular distribution of the trees in the stands. In connection with this, I will add that we know little about the benefits of interplanting specific selections for pollen production to increase seed set in black walnut plantations. The benefits of providing pollen sources to increase fruit set in pecan orchards are well known.

Payne: There have been several recently published studies on fruit drop and alternate year bearing in pecan. Pecan is notorious for bearing a tremendous crop one year and then having an off year the next one. The importance of interplanting with varieties specifically selected for good pollen production is well recognized in pecan culture. The state of the art is such that when a grower selects one variety for planting it is possible to tell him what other varieties he needs to plant with it to ensure good pollination. Another aspect of this problem is that in some years when pecans are subjected to a cold spring, although there is an abundant production of female flowers, they will fail to set because of poor pollen production that year.

Funk: Squirrels contribute to the poor pollination problem. They like to feed upon developing catkins. They will go to great lengths to creep out to the ends of branches and eat them.

Kuntz: In some of our stress tests in studying other disease relationships, we found that on very young walnut trees we could get a high seed set if we partially strangled, girdled or root cut them. Seed from these stressed trees were viable and produced seedlings.

ROOT ROT OF BLACK WALNUT SEEDLINGS CAUSED BY PHYTOPHTHORA CITRICOLA

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ABSTRACT.--Black walnut seedlings were inoculated with isolates of Phytophthora citricola, P. cinnamomi, P. cactorum and Cylindrocladium scoparium in comparative pathogenicity tests. Only P. citricola produced the typical root rot symptoms found in walnut seedling beds and after winter storage in nurseries in northern Indiana. Isolation of P. citricola from both diseased plant tissues and directly from the soil varied with the selective medium used. Baiting techniques were also used in attempts to isolate P. citricola from soil, however, results were erratic and could not be quantified. Infection of black walnut seedlings by P. citricola is dependent primarily on soil moisture and is influenced by soil temperature. Infection incidence was highest when soil moisture was 100% saturation (SC) for 72 hr and soil temperature was 22.5°C. When the inoculum density of naturally infested soil was increased by addition of oospores of P. citricola (50-5000/g soil) and soil moisture and temperature controlled, the infection incidence increased. No significant reduction in disease incidence occurred in plots using drench treatments with the fungicides Dexon, Truban and Nurelle. Measurable but not statistically significant reduction of root rot incidence in heeling-in beds occurred when seedlings were carefully graded and the roots dipped in Captan (4 lb/100 gal) before storage.

Black walnut is a highly valued component of the American decidious forest. The chocolate brown wood color, durability and ease with which the wood is worked places walnut in high demand in both the lumber and veneer industries in the U.S. and abroad. A large portion of the black walnut harvested annually comes from Indiana. Recent figures indicate that Indiana produces nearly one third of the total veneer quality logs and ranks high in total walnut timber production (1).

Because of the high price and demand, along with a dwindling supply of walnut trees, there has been a strong demand for walnut planting stock. Nursery production of black walnut seedlings doubled in the eastern U.S. from 1967 to 1971 (7).

In Indiana, two state tree nurseries produce most of the black walnut seedlings. The Jasper-Pulaski Nursery, located near Medaryville, Indiana, services the northern half of the state and produces approximately 300,000 seedlings annually. Seedlings are grown from seed collected locally. The seed are hulled and Fall-sown in nursery beds, which are covered either with hydro-mulch or wild hay to reduce damage from severe winter frost and losses from rodent pilferage. The seedlings are lifted the following Fall and are graded, bundled and placed in heeling-in beds for Winter storage.

In recent years, seedling production has been sharply curtailed in this nursery and elsewhere by a root disease affecting plants both in the seedbed and during winter storage. In the seedbed, infection may occur at any time after germination begins and causes a rather sudden chlorosis and wilting of the shoot, while the root system shows distinct water-soaked, greenish black lesions located at or near the root collar. The root lesions progress rapidly and the above ground portion of the seedling turns black. Roots of infected dormant plants in the heeling-in beds resemble those of diseased plants in the seedbed and in both cases mortality is almost certain.

In general, infected seedlings occur more commonly in the more poorly drained portions of the nursery beds. Infected plants occur in spots or patches that suggest either the spread of the causal agent from seedlings initially infected to adjacent plants or specific soil conditions which favor infection.

In 1970, Green and Pratt (6) implicated the fungus Phytophthora citricola Sawada as the causal agent of this root rot. Later, Green (5) indicated that at least three species of the genus Phytophthora were reported causing a root rot of seedling black walnut. In addition, Cordell and Matuszewski (2) reported the fungus Cylindrocladium scoparium causing a root rot of walnut seedlings in nurseries in Kentucky.

The objectives of the current study were:

1. To determine whether species of Phytophthora other than P. citricola are involved in this disease and whether other fungi such as Cylindrocladium scoparium occur in a disease complex.
2. To determine factors affecting seedling infection, including soil moisture, soil temperature and inoculum density.
3. Screening of selected fungicides to reduce disease incidence in the seedbed and during Winter storage.

PATHOGENICITY TESTS

Four species of fungi were used in a comparative pathogenicity study on black walnut seedlings. These included Phytophthora citricola (source - Indiana and Wisconsin; host - walnut), P. cactorum (source - Ohio; host - apple), P. cinnamomi (source - Ohio; host - rhododendron) and Cylindrocladium scoparium (source - Indiana; host - walnut). Black walnut seedlings were grown from stratified seed in sterile sand and inoculated when plants were approximately 25 cm tall. The seedlings were lifted, the sand removed by washing gently under the tap and then wounded with a sterile blade to make a small tissue flap at the root collar. A 1 cm piece of mycelial mat from the test fungus was placed in the wound, which was then closed and covered with petrolatum. Ten seedlings were inoculated with each test fungus and check plants were wounded but not inoculated along with non-wounded controls.

The seedlings were placed in large plastic pots (5/pot) in a 50/50 sterile sand-vermiculite mixture and incubated under greenhouse conditions for 2 weeks. The seedlings were then lifted, rated from symptoms development and attempts made to reisolate the pathogen from the host tissues. The seedling roots were washed in tap water, surface sterilized with 1% NaOCl for 2 minutes and tissue sections from the margin of the affected root area placed on the selective medium. Seedlings inoculated with Phytophthora sp. were placed on PNP agar (Potato dextrose agar (PDA) + pimaracin - 100 ppm, neomycin - 50 ppm and penicillin G - 35 ppm) described by Eckert and Tsao (4). Seedlings inoculated with C. scoparium were plated on PDTA (PDA + Tergitol NPX - 200 ppm and aureomycin - 30 ppm) (8).

Only P. citricola produced the typical extensive, water-soaked, greenish-black root lesions in the inoculated seedling root system. Neither P. cactorum or P. cinnamomi progressed much beyond the wound area of inoculation. These differences may be due, at least in part, to the fact that these latter two Phytophthora species were from hosts other than walnut. None the less, only P. citricola produced typical root symptoms and could be readily reisolated from root tissues of inoculated plants. Phytophthora cactorum was reisolated from only 20% of the inoculated seedlings and P. cinnamomi was not reisolated at all.

Seedlings inoculated with Cylindrocladium scoparium developed longitudinal cracks at the root collar and brown, necrotic lesions which were sunken into the root tissues. These symptons are quite distinct from those produced by P. citricola and the fungus was readily reisolated from infected tissues.

Effects of soil moisture, soil temperature and inoculum density

The saturation capacity (SC) of soil from the Jasper-Pulaski Tree Nursery was determined as a percent of dry weight by the methods described by Couch et al. (3). Oospores (I) of P. citricola were added to naturally infected soil (NS) in the first experiments at the rate of 500 oospores/g soil. In the second series of tests, oospores were added to the top 2.5 - 5.0 cm of the soil in containers at the rates of 0, 50, 500 and 5000 oospores/g soil.

In the first series, stratified walnut seed that were germinating (radicle emerging) were planted (5/pot) in large ceramic containers (25 cm X 25 cm) in controlled climate chambers at 15°C and 22.5°C. When the seedlings were 3 weeks old, the soil moisture was adjusted to 100% SC for 24 hr and 72 hr, respectively, in two different treatments. After treatment, the drains were opened and containers watered routinely on a 3-day schedule. Checks were maintained in naturally infested and oospore-amended NS with free drainage and controls were in previously sterilized NS with free drainage. Treatments were replicated 3 times and incubated for 3 weeks. The plants were then lifted, rated for symptoms and isolations attempted from the roots on PNP agar.

The second test series included NS + I at rates 0, 50, 500 and 5000 oospores/g soil incorporated in the upper 2.5 - 5.0 cm of soil. Germinating seed were planted (5/container) and the soil moisture adjusted to SC 60%. Treatments were replicated 3 times and the

incubation period was 4 weeks at 15°C and 22.5°C. The seedlings were then lifted, rated for root and top symptoms and isolations attempted from the root tissues on the PNP agar.

The results of the experiments to determine the effects of soil temperature, soil moisture and increased inoculum density on root infection by P. citricola are presented in Table 1.

There was relatively little difference in the infection incidence in all treatments at the two different soil temperatures (15° and 22.5°C). The infection incidence did increase, however, when the soil moisture was increased to 100% SC for 24 hr and 72 hr, respectively, and was greatest when the inoculum in naturally infested soil (NA) was increased by the addition of oospores (500 oospores/g).

Reisolation attempts were made on all plants showing typical root rot symptoms using the PNP selective medium. P. citricola could be recovered from only approximately 50% of the plants sampled. This is due, primarily, to overgrowth by other, fast growing fungi which are present. None of these are known pathogens of walnut seedlings, however.

When the inoculum density of P. citricola was increased in NA soil by the addition of oospores at the rates of 50, 500 and 5000/g soil in the top 2.5 - 5.0 cm of the container, the infection increased accordingly, as shown in Table 2.

There was also a slight increase in infection incidence, as indicated by symptom development, at 22.5°C compared to 15°C. Also, the success in reisolation of P. citricola was approximately 50% of the plants exhibiting root rot symptoms.

Table 1. Effects of different soil moisture, temperature, and inoculum levels on the infection of black walnut seedlings by Phytophthora citricola.

Temperature	Soil Moisture	Soil[1]	Symptoms-[2] # plants	Isolation-[3] P. citricola
15°	free drainage	NS + I	1/15	0/1
	100% SC - 24 hr.	NS + I	8/15	3/8
		NS	4/15	2/4
	100% SC - 72 hr.	NS + I	13/15	5/13
		NS	10/15	3/10
22.5°C	free drainage	NS + I	2/15	0/2
	100% SC - 24 hr.	NS + I	10/15	3/10
		NS	7/15	0/7
	100% SC - 72 hr.	NS + I	11/15	5/11
		NS	8/15	6/8

[1]NS = naturally infested soil; NS + I = naturally infested soil plus inoculum (500 oospores/g soil).
[2]Number of plants showing typical root rot symptoms over the total number of plants.
[3]Number of plants yielding P. citricola in isolation attempts on PNP over the total number of plants showing typical root rot symptoms.

Table 2. Effects of varying concentrations of oospores of Phytophthora citricola on infection of black walnut seedlings.

Temperature	Oospore[1] Concentration	Symptoms-[2] # plants	Isolation-[3] P. citricola
15°C	0	6/15	2/6
	50	5/15	0/5
	500	8/15	5/8
	5,000	10/15	4/10
22.5°C	0	8/15	2/8
	50	9/15	4/9
	500	11/15	6/11
	5,000	11/15	4/11

[1]Concentration of oospores of P. citricola/g silica sand one inch in depth of the soil surface.
[2]Number of plants showing typical root rot symptoms over total number of plants.
[3]Number of plants yielding P. citricola in isolation attempts using PNP over total number of plants showing root rot symptoms.

CHEMICAL CONTROL - NURSERY SEEDBEDS AND HEELING-IN BEDS

Three candidate fungicides were tested for control of Phytophthora root rot of walnut seedlings in the seedbed. These included Dexon 35% WP (Chemagro Corp.), Truban 25% EC (Mallenckrodt Chem Works) and Nurelle 1/2 lb/gal (Dow Chem Corp). These fungicides were applied as a drench according to recommended rate (X) and twice the recommended rate (2X). Treatment plots (4 ft X 25 ft) were designated in existing seedbeds at the Jasper-Pulaski tree nursery. All treatments were replicated 3 times. Treatments were made when approximately 25% of the seed had germinated and was repeated 21 days later.

After 6 weeks, seedling counts were made to determine the disease incidence in treatment plots compared to controls. A frame 2 ft X 4 ft was placed at random across the seedbed in treatment plots and all plants within the frame area were counted. Dead or diseased seedlings were recorded after lifting to inspect the root system for symptoms typical of Phytophthora root rot.

Results of the fungicide drench treatments are presented in Table 3.

The incidence of infection of walnut seedlings by P. citricola was low, as shown by the infection in the check plots. Therefore, it is difficult to draw conclusions from these results. All treatments appeared to reduce infection incidence, with Nurelle at the 2X rate the best treatment.

After walnut seedlings were lifted in the Fall, graded and bundled (25/bundle) for Winter storage, treatments were made using the fungicide Captan 50% WP at the rate of 4 lb/100 gal water. Seedling bundles (total - 100 bundles) were immersed in the fungicide for several minutes to insure complete coverage, drained and placed at random in the heeling-in beds.

When the heeling-in beds were opened in the Spring, the treated bundles were opened and the number of infected seedlings recorded. A like number (100) of untreated bundles were taken from the heeling-in bed at random and the number of infected seedlings recorded. The results were as follows: Captan dip - 2500 seedlings - infected - 48 (1.9%) and untreated control - 2500 seedlings - infected - 188 (7.5%). The fungicide dip reduced disease incidence by almost 75% over the untreated controls. This treatment has been in use for 2 years and results are somewhat variable. When the infection incidence is low, i.e. less than 10%, there is a substantial reduction in infection in treated seedling lots. However, if infection is high (25% +) the fungicide treatment was not as effective. This suggests that, under these conditions, the major losses are from incipient infection of seedlings that was not detected during grading and bundling. The fungicide dip serves only as a protectant

and would not prevent subsequent symptom development in these infected seedlings.

Table 3. Fungicide drench treatment of seedbeds to reduce root rot of black walnut seedlings caused by Phytophthora citricola.

Chemical	Rate	Appl.	Seedlings Total	Seedlings Infected	% Infected
DEXON 35 WP	1½ lb/100	2	381	11	3%
	3 lb/100	2	345	8	2.3%
TRUBAN 25% EC	4 oz/100	2	401	4	1.0%
	8 oz/100	2	360	9	2.5%
NURELLE	4 oz/100	2	380	7	2.0%
	8 oz/100	2	321	1	0.3%
CHECK	---		366	16	4.3%

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GROUP DISCUSSION

Kessler: Is there a bioassay to detect Phytophthora citricola in the soil?

Green: We have attempted to isolate citricola from the soil but quantitatively it is very difficult to do so because of erratic recovery rates with both baiting techniques and special isolation media.

I should also mention that walnut is the most seriously affected species in our Indiana nurseries. However, Chinese chestnut is also quite susceptible and the oaks--but to a lesser extent. Fibrous rooted species are scarcely affected at all.

Kuntz: Compared to disease development in the heeling-in beds, what are the results in cold storage?

Green: Where we have overwintered stock in cold storage, root rot has been disastrous. We are planning to set up experiments where the incidence of root rot will be measured following several kinds of handling treatments following lifting, including cold storage and outdoor storage in heeling-in beds.

Shigo: You say the infection starts at the root crown-collar zone, but isn't it more exact to say that it starts from the secondary roots?

Green: Yes.

Shigo: How soon do mycorrhizae form on these young plants?

Green: In terms of either their mycorrhizal colonization or extent of colonization, I don't know. One of the problems, of course, in these nurseries is that methyl bromide is routinely used as a soil fumigant. Because of this, mycorrhizal fungi may be reduced to low populations in these soils. In looking through these nurseries one notices instances, dogwood for example, where the trees grow extremely slowly the first year and then suddenly shoot up a foot or a foot and a half the next year. These spectacular growth increases are probably correlated to mycorrhizal development on the roots.

Roth: Do you find oospores in the soil?

Green: We were able to detect 10-25 oospores per gram of nursery soil. Oospore concentrations in soil were difficult to quantify.

Nicholls: Why do you believe you have a Phytophthora instead of a Cylindrocladium root rot which is present in other nurseries?

Green: The symptoms of Cylindrocladium are quite distinctive. We have routinely run isolations from decayed roots with media selective for Cylindrocladium and have not recovered the fungus. In southern Indiana at the Vallonia Nursery the major root rot problem is Cylindrocladium; there we have no problem recovering it. I think there may be a distinct environmental limitation to the distribution of Phytophthora--south of the Ohio Valley area Phytophthora is not common.

Kuntz: What are the symptoms of Phytophthora on outplanted walnuts of any size?

Green: I have not seen Phytophthora symptoms on anything other than first-year outplanted seedlings. I feel strongly that it is pretty much a nursery seedling problem. Losses from it, however, can be fairly high during the first year in outplanting.

LaMadeline: Is walnut fall planted as well as spring planted?

Green: In our area it's nearly all spring planted.

LaMadeline: Do you think that fall planting would be similar to heeling-in of lifted stock--that you would get more losses from fall planted than from spring planted stock?

Green: I don't know. This is something we should investigate.

LaMadeline: In conifers some consideration is being given to fall planting to spread the work load more evenly. In the fall-planted conifer plantations we have looked at we are finding root rot and suspect that some of them will fail because of it.

CYLINDROCLADIUM ROOT ROT OF BLACK WALNUT SEEDLINGS

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ABSTRACT.--Cylindrocladium root rot of black walnut seedlings, incited by C. floridanum and C. scoparium, is a major limiting factor in the production of healthy seedlings in southeastern forest nurseries. Generally, at the Griffith State Forest Nursery, Clayton, NC, root rot was evident first at the tip of the seedling taproot and colonization appeared to progress up the vascular system. At this nursery, control of Cylindrocladium root rot with Smite 15G (sodium azide, Pittsburgh Plate Glass Ind., Inc.) at 224 kg ai/ha, applied by the plowdown method, was comparable to MC-33 (methyl bromide 66%, chloropicrin 33%) at 504 kg ai/ha. Smite at 67 kg ai/ha was only marginally effective in disease control. Fumigation of plots resulted in reduction of Cylindrocladium microsclerotium populations. Separate tests indicated that microsclerotia in artificial clay clods greater than 5 cm in length were not killed with Smite. Effective disease control is dependent upon proper seed-bed preparation, especially in high clay soil nurseries.

At the Augusta Forestry Center, Crimora, VA, a small-spored Cylindrocladium sp. with clavate to popillate vesicles, identified as C. parvum, was consistently isolated from necrotic black walnut roots and seed-bed soil samples. Typically, low Cylindrocladium populations were recovered from soil samples collected from the root zone of necrotic black walnut seedlings; however, a nursery-wide survey indicated that Cylindrocladium inoculum is distributed in most parts of the nursery. Microsclerotium populations recovered from dead seedling roots were appreciably higher for C. parvum (mean = 1107 propagule/g tissue) than for C. floridanum and C. scoparium (collective mean = 385 propagules/g tissue). In greenhouse tests, limited pathogenicity of C. parvum on black walnut seedlings was demonstrated.

Root rot of black walnut incited by C. scoparium and C. floridanum, has been demonstrated recently to be a major limiting factor in the production and survival of black walnut seedlings. Pathogenicity tests indicate that black walnut is one of the most susceptible tree seedlings to Cylindrocladium root rot in southern forest nurseries (4). In 1968, Filer (5) reported that thousands of black walnut seedlings were killed by C. floridanum in a forest nursery in Tennessee. Cordell (4) estimated that black walnut seedling losses were over 50% in at least six southeast forest nurseries in the last five years. Root rot of black walnut has occurred in every southeast forest nursery where black walnut is grown.

Recently, C. crotalariae, incitant of Cylindrocladium black rot of peanut, was isolated from a West Virginia forest nursery soil (13). Cylindrocladium crotalariae is one of the most pathogenic Cylindrocladium spp. to black walnut seedlings and a wide variety of southeast forest nursery tree seedlings (4).

Initial symptoms of Cylindrocladium root rot of black walnut include small, necrotic lesions on the tap and lateral roots. These necrotic areas may enlarge and coalesce until the entire tap root is necrotic. Longitudinal cracking of the taproot often is associated with root rot. Pronounced wilting and foliar necrosis may be observed although this phase is relatively insignificant in comparison to root decay (4) (fig. 1)

Efforts to satisfactorily control Cylindrocladium root rot in forest nurseries have met with only partial success. Several chemical fumigants, including Mylone (3, 5-dimethyl-1, 3, 5, 2H-tetrahydrothiazine-2-thione, 50%, inert ingredients, 50%) (25), Vorlex (methyl-isothiocyanate 20%, chlorinated C_3 hydrocarbons, 8%) (25), Telone C (1,3-dichloropropene and related chlorinated C_3 hydrocarbons 85% + trichloronitromethane, 15%) (22), methyl bromide and MC-33 (methyl bromide, 67% and trichloronitromethane, 33%) (4, 11, 25) have had limited success in controlling Cylindrocladium root rot in forest nurseries.

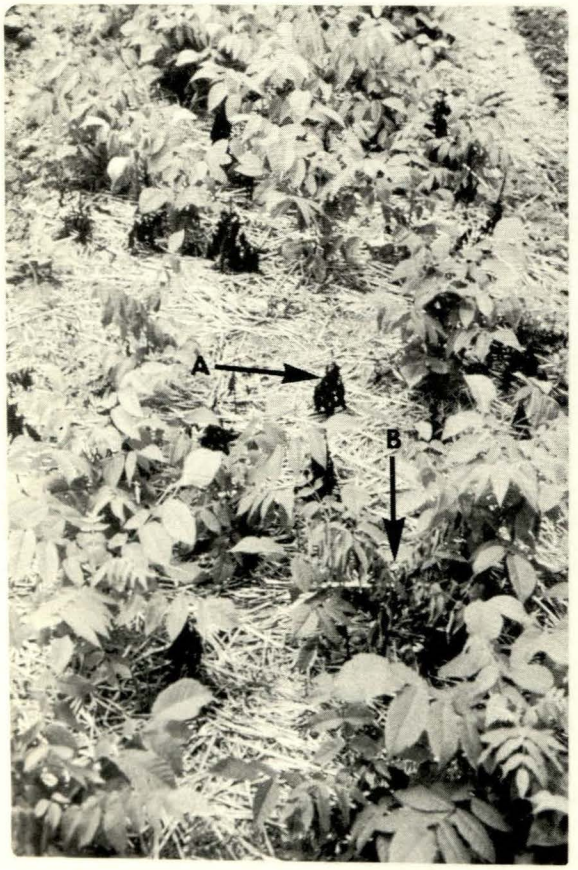

Figure 1.--Characteristic Cylindrocladium root rot symptoms of black walnut seedlings in naturally infested soil, including poor stand, dead seedlings (A) and wilting (B).

One of the most promising chemicals for the control of Cylindrocladium spp. is sodium azide (Smite 15G). Smite has effectively controlled Cylindrocladium black rot of peanuts incited by C. crotalariae, in greenhouse (10) and field (18, 20) tests at rates from 33 to 120 kg/ha. Weaver (26) obtained 100% control of Cylindrocladium root rot of peaches, incited by C. floridanum, in greenhouse tests with potassium azide at 20 mg/kg soil.

METHODS AND MATERIALS

In the fall of 1975 and 1976, fumigation test plots for the control of Cylindrocladium root rot of black walnut were established at the Griffith State Forest Nursery, Clayton, NC. Each plot was 10.4 x 1.8 m. A 0.61 m buffer zone at each end of the plot was not treated; therefore, the total fumigated area was 9.1 x 1.8 m. Five treatments, each replicated four times, were randomly distributed among the 20 test plots in a split-plot design. The efficacy of Smite (Sodium azide, PPG Industries, Inc., Pittsburgh, PA) granules (15% a.i.) and MC-33 at different rates and application methods were evaluated. The soil type of the upper profile was a loamy sand (sand = 83.6%; silt = 12.4% clay = 4.2%) although a high-clay subsoil horizon (45%) at varying depths was present.

Smite was applied by the plow-down method developed by Aaron Womble of PPG (unpublished). One-half of the Smite was applied with a Gandy gravity-flow granular applicator, and then thoroughly disked into the upper 15 cm of soil. The plot was then deep plowed, inverting the upper layer containing the Smite. The second half of the Smite was applied and thoroughly disked into the upper 15 cm of soil. This procedure effectively distributed the Smite throughout the top of 20-30 cm of soil, depending on the depth of the plow layer. The MC-33 was applied by standard soil injection to a depth of 12-20 cm, following plow-down treatment of the plow layer. The soil temperature (15-cm depth) for the 1975 and 1976 treatments were 17 C and 10 C, respectively.

The 1975 treatments, made on October 23, were as follows: Smite at 67 kg ai/ha, Smite at 224 kg ai/ha, MC-33 at 504 kg ai/ha and two non-fumigated, but plow-down-worked, controls. All plots were tarped with 1-mil polyethylene.

The 1976 treatments, made on November 4, were modified based on 1975 results. The treatments were as follows: non-fumigated control; MC-33 at 542 kg ai/ha; Smite at 224 kg ai/ha, tarped; Smite at 224 kg ai/ha, no tarp; and Smite at 224 kg ai/ha, no tarp, but in this treatment a bedshaper was utilized to increase the depth of the root zone to 31-46 cm. Typically, the root zone in this nursery ranged from 22-23 cm in depth.

On March 23, 1976 and April 4, 1977, black walnut seeds were planted in the test plots. The planted seeds were mulched with approximately 2.5 cm of pine needles. On

November 4, 1976, and November 7, 1977, 10 random black walnut seedlings for each of four replications were dug up and the taproot was dissected to determine disease severity. The ratings were based on the following scale: 0 = healthy; 1 = necrosis at tip of tap root only (less than 5% of the taproot); 2 = necrosis extending slightly into root stele and cortex from root tip (less than 20% of tap root); 3 = necrosis of 20 to 50% of tap root; 4 = necrosis of more than 50% of tap root; 5 = dead.

Prior to fumigation in the fall and planting in the spring, five soil samples (0 - 10 cm depth) per plot were collected and placed in plastic bags with pinholes for gas exchange. Samples were stored at room temperature (26-28 C) until processing. The presence of Cylindrocladium inoculum in soil was determined by the azalea-leaf-trap method (15), due to the low inoculum levels present. Ten azalea leaves ('Hershey Red') were placed in each previously mixed soil sample and incubated for 5-9 d at 26-28 C in moist chambers. Following incubation, the leaves were surface-sterilized in 0.5% NaClO for 5 min, rinsed in sterile distilled water and the margins of necrotic lesions plated on sucrose-thiabendazole (TBZ) medium, selective for Cylindrocladium spp. (14).

Tissues from symptomatic walnut roots were surface sterilized for 3 min in 1.0% NaClO, rinsed in sterile distilled water and the margins of necrotic areas placed on Cylindrocladium-selective media (7, 14).

Artificial soil clods (1.3, 2.5, and 5.1 cm in length) were produced from two Cylindrocladium-free soils of different clay contents (43% and 8%), bulk densities (1.4 and 1.7) and field capacities (32% and 12% water) but equal pH values (6.2). Microsclerotia of C. crotalariae were placed at the clod center in a layer of artificially infested soil 1.2-cm thick. Smite granules (8% a.i.) were used in all experiments. Each of the soils (air dry) was thoroughly mixed with Smite at the rate of 50 µg/g soil, equivalent to approximately 112 kg ai/ha - 15 cm depth, for 30 min in a plastic bag before placing it in a plastic container (31 x 23 x 10 cm) to a depth of 4 cm, and then raising the water content of the soil to field capacity. The clods, containing no Smite, were randomly placed near, but not at the bottom of the 4-cm layer of Smite-treated soil or control soil during placement of the soils in the boxes. In addition, 20 g of microsclerotia-infested soil were spread over each of three Whatman filter papers (9-cm diam), and the papers were placed on top of the treated or control soils (to simulate microsclerotia in surface debris) in the containers. For soils receiving a surface treatment of Smite (10 µg ai/g soil), granules of the latter were spread evenly over the soil surface not covered by the three filter papers. Thus, no direct contact was made between the Smite and microsclerotia-infested soil. The containers with treated or control soils were covered with loose-fitting plastic lids. After 4d of incubation at 27C all microsclerotia-infested soils were assayed for C. crotalariae microsclerotium populations by the Krigsvold and Griffin method (14).

Field studies of Cylindrocladium populations at the Augusta Forestry Center, Crimora, VA were undertaken during the summer of 1975, 1976 and 1977. Soil samples (0-20 cm depth) were collected from black walnut seedbeds and assayed qualitatively by the azalea-leaf-trap method (15) and quantitatively by wet sieving and dilution plating (14). Cylindrocladium populations in rotted black walnut roots were determined by a modification of the Krigsvold and Griffin method (14) for Cylindrocladium soil population analysis. Severely rotted black walnut roots (50-g samples) were ground up in a Waring Blender for 5 min at high speed, followed by wet-sieving through 841-um (20 mesh) and 44-um sieve and washed into a beaker with 250 ml of sterile distilled water. The suspension was stirred for 30 sec with 10 ml of 5% NaClO and rinsed through a 44-um sieve for an additional 3 min. Dilutions of 1:25 (root tissue:sterile distilled water) were used and 1 ml was pipetted onto each of 10 petri dishes containing sucrose-TBZ selective medium (14). Cylindrocladium populations were determined from counting colonies developing on each of 10 petri dishes after 7 d incubation.

Tissue from margins of necrotic roots was surface sterilized for 3 min in 1.0% NaClO and rinsed in sterile distilled water prior to plating. Feeder roots were rinsed under running tap water for 30 min and plated on media selective for Cylindrocladium (7, 14).

To survey the Augusta Nursery for Cylindrocladium inoculum, soil samples were taken throughout the nursery at 15-m intervals along approximately 150-m rows (approximately 75 m apart) during June and August 1977. The presence of Cylindrocladium spp. was determined by the azalea-leaf-trap method (15) previously described.

For pathogenicity tests, black walnut seeds were grown in a potting mixture containing 1 part vermiculite, 1 part weblite (an expanded shale product, Weblite Corp., Roanoke, VA 24029), and 0.5 part peat moss. For inoculum, clones of C. floridanum, C. scoparium and C. parvum isolated directly from necrotic black walnut roots were grown in a liquid medium (12) for 6-9 mon at 25 C in continuous darkness. In 1976, seedlings were transplanted into 26.7-cm diam. pots containing potting mix artificially infested with 10 C. floridanum microsclerotia/g mix or 150 ml of C. parvum mycelium-chlamydospore preparation per pot. The latter was prepared by washing the C. parvum mycelium-chlamydospore mat for 10 min in tapwater, followed by grinding the washed mat in a Waring Blender for 5 min. In 1977 and 1978 seedlings were transplanted into 12 cm (diam) plastic pots and placed in controlled temperature (25 C) tanks. In 1978, seedlings were grown under continuous light. Tap roots of eight-week-old black walnut seedlings were wounded (approximately 1.5 cm of the root surface was peeled off) and inoculated with a washed mat (15 mg portions, dry weight) of C. scoparium and C. parvum alone or in combination. Wounded, uninoculated plants served as controls. Each treatment was replicated ten times in 1977 and twenty times in 1978. Seedlings were harvested after five weeks incubation, and rated according to the disease severity index previously described. Pathogen isolation from margins of necrotic roots was done as described above.

RESULTS

Control of Cylindrocladium Root Rot

Root disease severity ratings from the 1975-76 test indicated that more healthy seedlings (disease class 0) were obtained from plots fumigated with 224 kg ai/ha Smite than with other treatments (table 1). However, when the probable effect of root pruning or undercutting is considered (combined disease classes 0 and 1) control of root rot with MC-33 (405 kg ai/ha) and Smite (224 kg ai/ha) may be comparable. Root disease index ratings for Smite (224 kg ai/ha) were significantly lower than both controls, but were not significantly different from the MC-33 treatment ($P = 0.05$). Smite at 67 kg ai/ha was only marginally effective in disease control. Azalea-leaf-trap assays of soil samples collected from treatment plots indicated that the soil fumigations generally resulted in inoculum decreases.

The 1976-77 chemical treatments were modified and the plot location was moved to an area believed to contain higher levels of Cylindrocladium inoculum than in the 1976-77 plots (C. E. Cordell, personal communication). However, azalea-leaf-trap assays indicated that inoculum levels were comparable to the 1975-76 levels (mean isolation percentage from traps of soil samples prior to fumigation = 9%). Compared to the 1975-76 severity ratings, disease ratings were low throughout the plot. The mean percent of living plants in all treatments in disease severity classes 0 and 1 was 87%. No treatments were significantly different from the control ($P = 0.05$). Further, measurements of lengths of healthy seedling tap roots in each treatment were not appreciably different. However, chemical treatments reduced the Cylindrocladium inoculum level, based on azalea-leaf-trap assays. In both years, C. floridanum was recovered from margins of symptomatic black walnut roots. Percentage of successful isolation of C. floridanum from necrotic roots was approximately 25%.

In most cases, root rot of seedlings was evident at the tip of the tap root for both control and chemical-treatment plots, and colonization appeared to progress up the vascular system for many plants (fig. 2). Initial necrotic symptoms were sometimes evident at the root crown. In some instances, taproot elongation was restricted by the presence of a high-clay subsoil (45% clay) located close to the soil surface. Observations indicated that much of the root rot was associated with this high-clay soil or the interface of the plow layer and the high-clay soil (fig. 3).

Separate experiments indicated that fumigation of low-clay soil clods (1.3 to 5.1 cm in length) with Smite resulted in a complete kill of artificially infested microsclerotia. In contrast, all microsclerotia in fumigated, high-clay soil clods of 5.1 cm in length were not killed, (32% of the microsclerotia survived) although no microsclerotia were recovered from fumigated clods of 1.3 and 2.5 cm in length. When a surface treatment of Smite was made in addition to the standard Smite soil-mix, microsclerotia in large (5.1 cm) high-clay clods were killed.

Biology of Cylindrocladium spp. at the Augusta Forestry Center, Crimora, VA

A small spored specie of Cylindrocladium, resembling C. parvum, was consistently recovered from diseased black walnut roots and from soil at the Augusta Forestry Center. Conidia were one septate and ranged in size from 9.5 - 21.4 x 2.1 - 4.3 µm (mean = 15.5 x 3.0 µm).

Table 1. Effect of Smite and MC-33 chemical treatments on Cylindrocladium root rot development of black walnut seedlings at the Griffith State Forestry Nursery, Clayton, NC, in 1975-1976.

Treatment[a]		Rate - kg (ai/ha)	Percent of live plants in disease severity class[b] 0	1	2	3	Percent Dead plants[c] 4	5
MC-33	yz	504	52.5	32.5	10.0	5.0		
Smite	y	34 + 34 plow-down method	40.0	22.5	37.5			
Smite	z	112 + 112 plow-down method	70.0	12.5	17.5			
Control I	xy		32.5	37.5	22.5	5.0	2.5	3.0
Control II	x		22.5	35.0	20.0	12.5	5.0	13.0

[a]MC-33 = methyl bromide 66%, chloropicrin 33%, Smite = sodium azide, 15% granule. Treatments followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple range test. Control I and Control II were identical entries.

[b]Class values determined by dissections of seedling taproot.

Percent of 40 random black walnut seedlings, 10 seedlings per replication for each of four replications.

0 = healthy; 1 = necrosis at tip of taproot only (less than 5% of the taproot); 2 = necrosis extending slightly into root stele and cortex from root tip (less than 20% of taproot); 3 = necrosis of less than 50% of taproot; 4 = necrosis of more than 50% of taproot; 5 = dead.

[c]Percent of total seedlings, ave. 40 seedlings per replication, 4 replications per treatment.

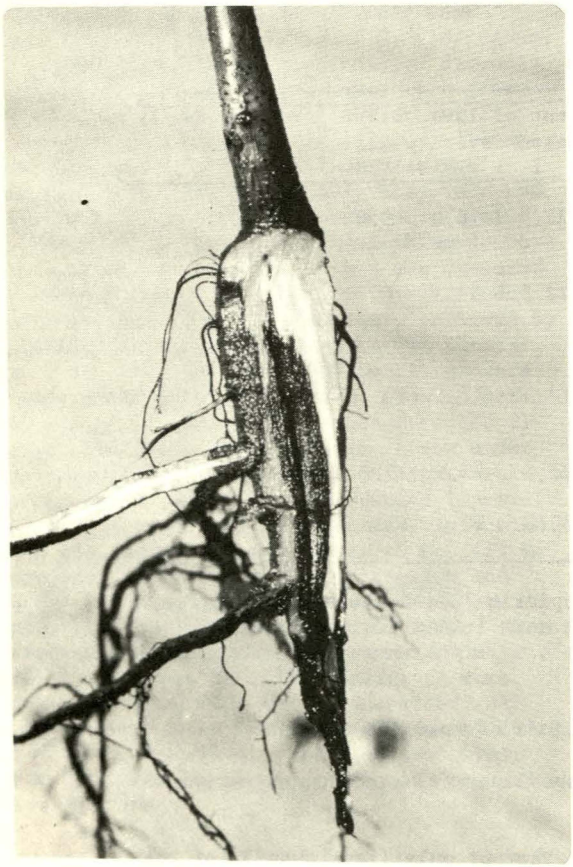

Figure 2. Cylindrocladium root rot of black walnut seedlings.

Vesicles were abundant but extremely variable in morphology (clavate to papillate) and size [11.9 - 59.5 x 2.4 - 14.3 µm (mean = 26.8 x 6.6 µm)]. Unlike C. crotalariae, C. floridanum and C. scoparium which produce microsclerotia, this fungus produces chlamydospore-like structures. This species will be referred to as C. parvum in the following sections.

Isolations from azalea-leaf-trap assays of soil samples collected from the rooting zone of necrotic black walnut seedlings and soil dilution plating indicated that the population of Cylindrocladium spp. was generally low at the Augusta nursery. Cylindrocladium parvum was isolated from azalea-leaf-traps of soil more frequently than C. scoparium and C. floridanum (mean of 9 soil samples = 34% for

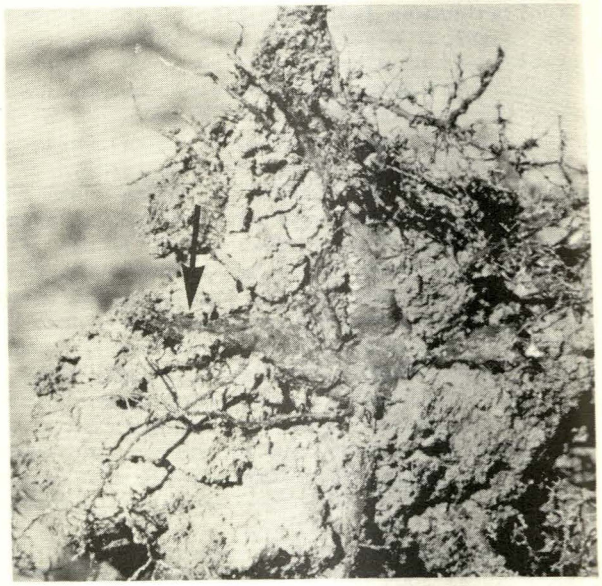

Figure 3. Association of root rot of black walnut seedlings (arrow) with high-clay soil.

C. parvum and 3% for C. scoparium and C. floridanum). Quantitative population assays in 1976 by the soil-dilution method (14) yielded a mean of 9.9 propagules/g soil (range = 3-17.6 propagules/g soil) of C. parvum for three seedbed soils containing many dead black walnut seedlings. The mean population of C. scoparium was 1.0 propagule/g (range = 0 - 2.4 propagules/g soil), whereas C. floridanum was recovered only infrequently. Populations in soil samples collected from the 1975 black walnut seedbeds were lower. The mean population of C. parvum, C. floridanum, and C. scoparium from six soils collected from root zones of severely necrotic seedlings was 5 (range 2 - 13), 0 and 0 propagules/g soil, respectively by the soil-dilution method. No Cylindrocladium spp. were recovered in two trials using the Thies and Patton procedure (23) or the alfalfa-leaf bioassay method (3). Extremely high populations of C. parvum (mean = 1,107 propagules/g root) were found from five samples of dead seedling roots. Populations of C. floridanum and C. scoparium in severely necrotic roots were lower (mean = 385 propagules/g root) than for C. parvum.

Typically, a low percentage successful isolation of Cylindrocladium spp. from marginal necrotic tissue of seedlings with characteristic root rot symptoms was found using sucrose-TBZ medium (14). For C. parvum and C. scoparium, percentage isolation from 485 seedlings was 27.7% and 11.0%, respectively. Cylindrocladium floridanum was isolated infrequently. No Cylindrocladium spp. were recovered when tissues were plated on semi-selective media including acidified potato-dextrose and acidified Czapek-Dox agar (Difco).

Disease incidence and severity was high in the 1976 black walnut seedbeds, approaching high values in localized "hot spots" (55% of the bed area had an average of 40% seeding kill). In seedbeds of this block, root rot appeared to progress outward from centers as the season progressed. The incidence of root rot was appreciably lower (ca. 5%) in 1975.

A nursery-wide survey of seedbed soils indicated that Cylindrocladium spp. are widely distributed but that inoculum density (estimated from percent colonization of azalea-leaf-traps) is low. In a block never planted in black walnuts, no recovery of any Cylindrocladium spp. was found; however, the highest percentage recovery (22%) was found from soil samples collected from the site of the 1976 black walnut seedbeds. Recovery of Cylindrocladium spp. in the four other blocks in the nursery ranged from 6 to 11% (mean = 9%).

A low percentage root rot was found for black walnut seedlings inoculated with C. scoparium and C. parvum in 1976. No seedlings in potting mix artificially infested with C. parvum or C. parvum and C. floridanum developed root rot. Twenty percent (2/10) of seedlings grown in C. floridanum-infested mix developed root rot symptoms; however, necrosis was not evident in the root stele. The low percentage symptoms observed was probably due to excessively high greenhouse temperatures (maximum = 42.2 C). Soil temperatures above 30 C are unfavorable for Cylindrocladium root rot development of peach (27) and peanut (19).

In 1977, no control seedlings developed root rot but 20% and 30% of the C.parvum- and C. scoparium- inoculated seedlings, respectively, developed root rot. Cylindrocladium parvum and C. scoparium were isolated from margins of necrotic tissue.

In 1978, approximately one week after inoculation, one seedling inoculated with C. scoparium began to wilt and after two weeks, severe root rot symptoms, characteristic of Cylindrocladium root rot, were observed. Percentage incidence of root rot in seedlings inoculated with C. parvum, C. scoparium, and C. parvum plus C. scoparium was 15, 20, and 10%, respectively. Necrosis was observed in the root stele of 10% and 5%, respectively, of the seedlings in the C. scoparium and C. parvum treatments. Isolations from symptomatic roots yielded C. scoparium and C. parvum.

DISCUSSION

Chemical control tests, undertaken from 1975 to 1977, were complicated by the low level of root disease present. This is surprising because Cordell (4), in 1971, estimated that at least 70% of 75,000 1-0 black walnut seedlings had symptoms of Cylindrocladium root rot. In 1973, he repeatedly isolated C. scoparium from soil samples collected from the site of the 1971 epiphytotic. The test plots in the present study were located in the vicinity of the 1971 epiphytotic. The decreased disease observed in 1976-77, compared to 1975-76 must be due in part, to environmental conditions since differences in Cylindrocladium inoculum for both years was not apparent. An unusually dry summer in 1977 may have been a contributing factor in the low amount of root rot observed in the 1976-77 tests.

Control of Cylindrocladium root rot of black walnut seedlings is complicated by several factors. Cylindrocladium microsclerotia are capable of long-term survival (16, 17, 23) and successful infection can develop at low inoculum densities (9, 10). Thus, nearly complete kill of microsclerotia may be necessary for adequate control. Further, black walnut is a deep-rooted species and deep placement of fumigants is required to provide protection for the entire root system.

A high-clay horizon (18-28 cm below the soil surface), was observed in the treatment plots and was associated with root rot development in many instances. Decreased hydrazoic acid diffusion and thus penetration, as a result of low-percentage large-pore spaces, may reduce fumigant efficiency in high-clay soils. During seedbed preparation, clay clods with the smallest dimensions as large as 6.3 cm (mean size = 4.3 cm) were brought to the soil surface in some areas of the seedbed, and root rot was associated with this high-clay soil. To obtain maximum disease control seedbed soil must be disked or rototilled to eliminate all large soil clods. At the Griffith nursery, the depth of the plot layer was limited by the clay horizon close

to the soil surface, and pockets of sandy-loam soil were observed below the plow layer. Thus, complete mixing of chemicals by plowing and disking with soil was not accomplished. The highest incidence of root rot, as previously mentioned, occurred at the tip of the seedling tap root. This was probably due, in part, to the presence of viable Cylindrocladium microsclerotia in undisturbed sandy-loam soil pockets below the plow layer and at the interface of the plow layer and the high-clay soil.

The plow-down method offers a simple and efficient method to incorporate granular chemicals deep and widely distributed in the rooting zone. However, all Cylindrocladium microsclerotia were not killed by soil fumigation with high rates of Smite, as indicated by azalea-leaf-trap assays and root rot development. Thus, it appears that alternate control practices are necessary in combination with fumigation. Effective grading of seedlings together with root pruning and fungicide dips may offer such an alternative. Cordell (4) found that seedlings with more than 10% root rot and a stem base less than 9.5 diameter had a poor chance of outplanting survival. Similarly, grading black walnut seedlings based on lengths of healthy taproot may give a satisfactory estimate of outplanting seedling survival.

Previously, C. parvum has been associated with root rot of rose, grape and Telopea speciossima, but pathogenicity has not been demonstrated (1, 2). Cylindrocladium parvum is either a causal factor in the black walnut root disease or is a proficient secondary colonizer. The presence of C. parvum in the margins of necrotic roots and the extremely high populations in severely necrotic roots, argues against the latter. Greenhouse tests deomonstrated only limited pathogenicity by C. parvum, but similar results were obtained also with a known pathogen (C. scoparium). The Cylindrocladium isolates utilized in the present studies were obtained from active infections, transferred one to two times and stored under mineral oil. Thus, they should have been pathogenic. Possibly, resistance to Cylindrocladium root rot is quantitative and dependent upon host vigor and environmental conditions (19). The black walnut seedlings in the 1977 and 1978 pathogenicity tests were very vigorous, and provided with optimum levels of water, fertilizer and light. Further work is required to elucidate the role of physical and biotic environmental factors in Cylindrocladium root rot development of black walnut seedlings.

Distribution of Cylindrocladium spp. throughout the Augusta nursery appears to be dependent, in part, upon the black walnut cropping history of each location. For instance, no walnuts were ever grown and no Cylindrocladium spp. were isolated from soil samples collected from one block of nursery. Disease incidence and severity was appreciably higher in 1976 than in 1975, and the percentage recovery of Cylindrocladium spp. was greater from the block where the 1976 black walnuts were planted than from the 1975 block. Possibly, a greater number of microsclerotia were released into the soil upon decomposition of necrotic black walnut roots. At the survey sampling time (July), disease incidence and severity in the 1977 black walnut crop were low. Few soil samples from this block in the survey were positive for Cylindrocladium.

Soil air-drying and low soil temperatures (<6C) results in large decreases in germinability of Cylindrocladium microsclerotia (6, 8, 21, 24); however, partial reversal of the decreased germinability occur upon rewetting air-dried soils and incubation at 25 C of low-temperature-treated soils (8, 21). Impairment of microsclerotium germinability following exposure to drought or low soil temperature may affect survival, or delay and reduce disease development, even though a complete loss of viability does not occur.

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GROUP DISCUSSION

Green: You showed what appeared to be a mulch on the seedbed. Is that routine practice?

Roth: In this nursery they mulch with straw and in North Carolina they mulch with pine needles about 2-3 inches deep.

Green: Do you find Cylindrocladium associated with areas of poor soil drainage?

Roth: No. For example, much of our problem occurred right in the middle of the seedbeds which were raised a little bit higher than the poorer drained ends of the beds.

Green: In Indiana nurseries where the hydromulch was used the incidence of Phytophthora root rot was much higher because of the increased soil moisture retained at the surface.

Kuntz: In Wisconsin we have a somewhat different situation. Cylindrocladium levels are low in the seedbeds. Our real problems develop in the heeling-in beds. In the spring following heeling-in we come out with almost total losses of heeled-in bundles. Where do you think these infections come from? Are they latent infections that develop in a more favorable environment in the heeling-in beds or is it infection that occurs as a result of wounding during the lifting/heeling-in sequence?

Roth: In the Southeast they are not heeled-in--they are put in cold storage in bundles. The seedlings that have root rot when they are put into cold storage have a poor outplanting survival rate and those that appear healthy going into cold storage have a high survival rate. Wounding may also be a factor. In greenhouse inoculation tests when I wounded the plants I got a much higher infection rate.

Kuntz: If we leave the seedlings in the seedbed until spring and then lift them we avoid practically all of this problem. Nurserymen maintain, however, that they can't do all of this work in the spring and they've got to be lifted in the fall.

Nicholls: At the Wilson State Nursery in Wisconsin a loss of around 90 percent occurred in a bed of 200,000 walnut seedlings that were planted in an unfumigated bed. In this instance no root pruning or lifting injuries were present that could be related to the development of the root rot.

Shigo: Years ago, I worked on a similar crown and root rot problem of yellow birch and found that where many plants occurred in small areas of nursery beds there often was a salts accumulation problem in the upper soil levels. Have you ever considered this phenomenon as one of the factors involved in the root rot problem?

Roth: With Cylindrocladium, at least in this one nursery, with a high clay content, most of the infection was of the lower tap root. In other nurseries with soils with less clay the rot really wasn't limited either to the crown or lower tap root--it came in from lateral roots or roots at any location.

Shigo: But I am talking about the more or less severe alterations in salt concentrations that occur in the top 4-6 inches of soil.

Roth: With black walnut, the tap root gets a lot deeper than that and infections are seen down through 25 cm.

Green: You're thinking about root necrosis as a result of high salt concentrations?

Shigo: Salt as a contribution factor. Something's got to be weakened somehow, and I'm just wondering if this factor was one you've considered. You need to determine in your

layering effect if you had such a situation.

LaMadeline: Is there a relationship between Phytophthora and Cylindrocladium root rots to fertilization--especially nitrogen?

Roth: We didn't test this in the field. In the greenhouse those factors of light, moisture and nutrition which led to optimal walnut growth seemed to result in increased resistance to Cylindrocladium infections.

THE WALNUT CATERPILLAR, DATANA INTEGERRIMA G. & R.

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ABSTRACT.--A description of the adult, egg, and larval stadia of the walnut caterpillar, Datana integerrima, is given. In central Illinois there is 1 generation of the walnut caterpillar a year, but occassionally 2 generations occur during certain years. There are 2 generations a year in southern Illinois. First generation adults emerge in mid to late May in southern Illinois; 2nd generation adults emerge in late July. Larval feeding habits vary in the 1st, 2nd, and 3rd stadia. Larvae of the walnut caterpillar feed and survive only on species of Juglandaceae. Four species of Tachinidae: Diptera and 4 species of Ichneumonidae: Hymenoptera parasitize larvae of the walnut caterpillar; 5 insect predators and 2 spiders were captured while feeding on walnut caterpillar larvae; and the house mouse and white footed mouse feed on walnut caterpillar pupae. Foliar sprays of malathion, diazinon, acepthate, and Bacillus thuringiensis Berliner controlled 2nd and 4th instar larvae.

The walnut caterpillar, Datana integerrima, is an important defoliating pest of black walnut, Juglans nigra L. Such defoliation weakens trees and can lead to invasion by secondary insects (Kulman 1971). Defoliation also affects development of the nut. The kernal does not develop fully after a tree has been defoliated (Hixson 1941).

The insect occurs throughout eastern United States and in some areas of southern Canada (Baker 1972). The insects range extends as far west as Minnesota, Nebraska, Kansas, Oklahoma, and as far south as Pecos and Terrell Counties in southwest Texas (Hixson 1941, Neeb 1976).

The adult of the walnut caterpillar varies in size according to sex; the body length of the male (Figure 1) is ca. 2 cm and the female is ca. 2.3 cm in length. The scales of the head and upper thorax are a deep rust-brown and are displayed prominently above the wings when in a resting position. The forewing is dark beige with 4 bands of dark rust-brown traversing it from the anterior to the posterior wing margin; a 5th band is present, but it is usually conterminous with the 4th. The hindwing, lower thorax, and abdomen are pale beige. The upper abdomen is a rust color, but is much lighter than the upper thorax.

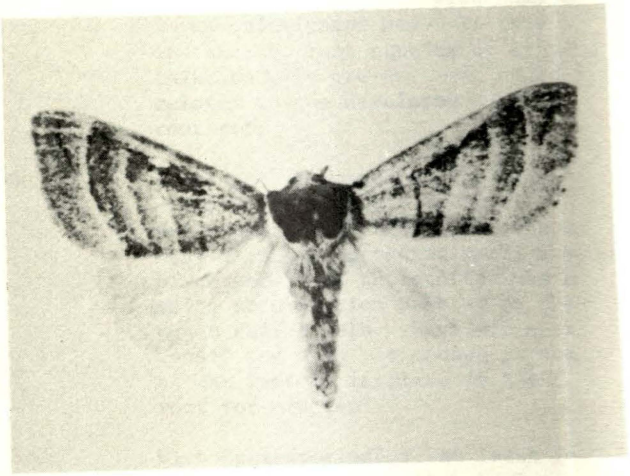


Figure 1.--An adult male of the walnut caterpillar, Datana integerrima.

The egg of the walnut caterpillar (Figure 2) is ca. 0.5 mm in diameter and 0.7 mm in height. The egg initially is very pale green with a white cap. Later the green disappears and becomes a very pale blue-green. The white cap does not change color. The eggs are cemented to the lower surface of the leaflet and are placed in masses with slightly curving rows. There is an average of 621 eggs in each mass.

The 1st instar larva is light green with a black head capsule (Figure 3). Several long white setae arise from black tubercles along the dorsal and lateral areas of the body. There is a black prothoracic and anal shield. Late 1st instar larvae show some red in the thoracic and lateral abdominal areas, and faint dorsal and lateral lines. The 2nd, 3rd, and 4th instar larvae are red-brown with black head capsules, white setae, and white dorsal and lateral lines the length of the body. The 5th instar larva is black with a black head capsule, white setae, and white dorsal and lateral lines; however,

the lines are not as evident as in earlier instars (Figure 4). The 2nd, 3rd, and 4th instars have a black prothoracic and anal shield. The shields are present in the 5th instar, but are the same color as the larval body and are not easily seen.

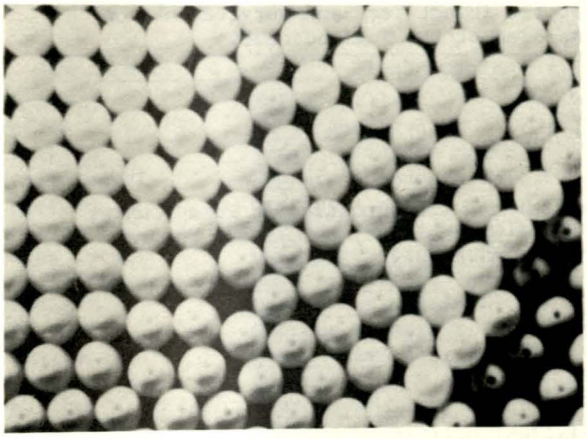


Figure 2.--Eggs of the walnut caterpillar, Datana integerrima, on the lower surface of a black walnut leaflet.

Figure 3.--1st instar larvae of the walnut caterpillar, Datana integerrima, on black walnut foliage.

Figure 4.--A 5th instar larva of the walnut caterpillar, Datana integerrima, on black walnut foliage.

The approximate body lengths of the various instars are as follows: 1st instar 2 mm to 4 mm; 2nd instar 4 mm to 9 mm; 3rd instar 9 mm to 14 mm; 4th instar 14 mm to 27 mm; and 5th instar 27 mm to 47 mm at maturity.

There are 2 generations of walnut caterpillar a year in southern Illinois, 1 generation in central Illinois with a potential 2nd generation. First generation adults begin emerging from overwintering pupae in mid May reaching a peak emergence in late May in southern Illinois. Second generation adults emerge in mid July reaching a peak in late July.

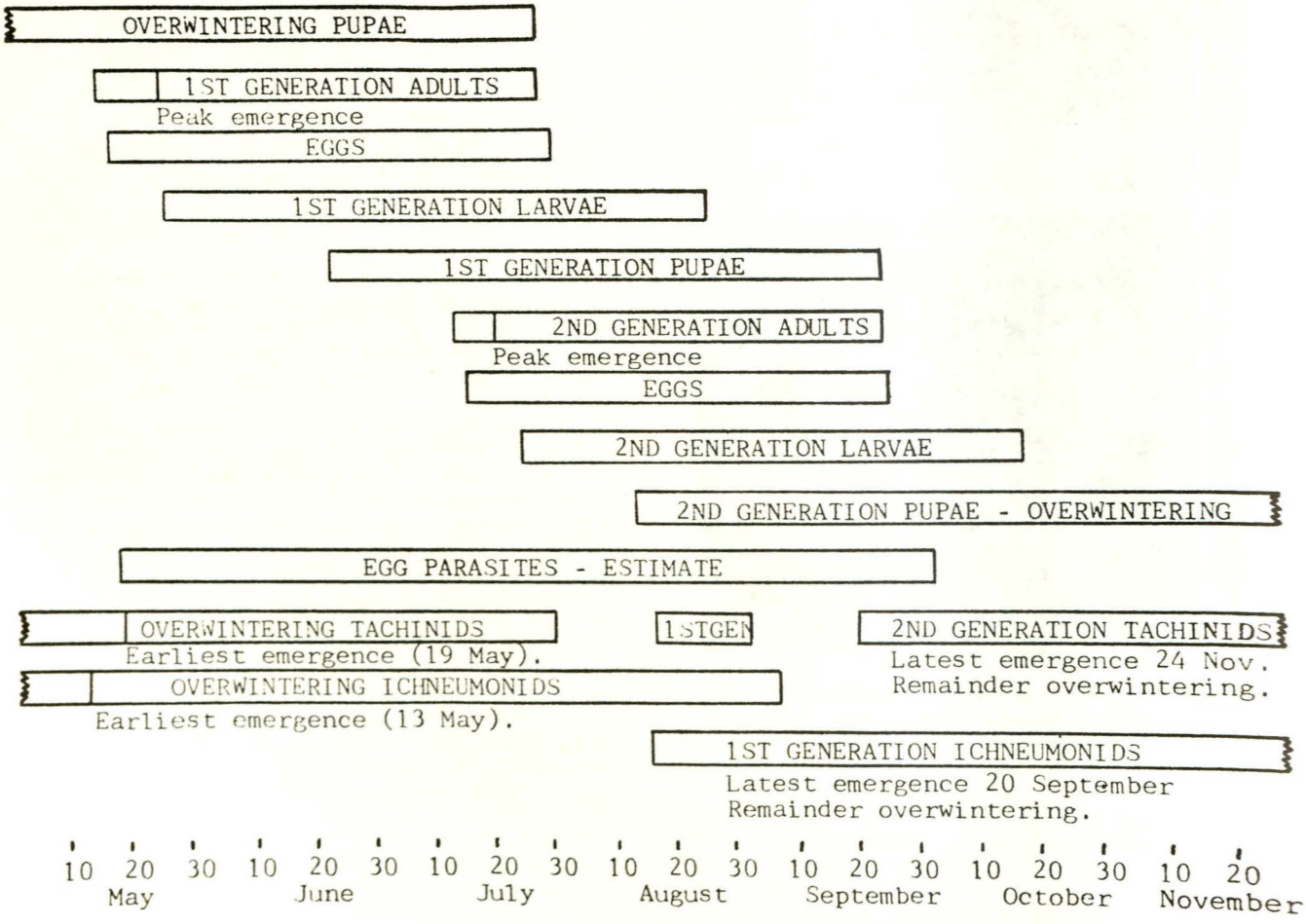
The adults oviposit in ca. 2 days after emergence. Egg masses are found on the lower surface of the leaflets and are generally on the lower branches of the host plant that is growing along the margins or in openings of hardwood forests, or on open grown trees such as ornamentals or those in plantings.

Larval eclosion occurs in ca. 9 days after egg deposition. The larvae mature in an average of 27 days; however, in very warm weather with temperatures averaging 25.2 degrees C the larval duration is shortened to ca. 19 days. Most 2nd generation larvae mature and drop from the trees to pupate in the soil by late September. The larvae require ca. 2 days to pupate, form no cocoon, and most pupate from 1 to 2 cm deep in sod.

The seasonal history of the walnut caterpillar and it's parasites is shown in table 1.

Host plants include black walnut, Juglans nigra L., butternut, J. cinerea L., various species of hickory and pecan, Carya sp., and, where planted in the insects range, English or Circassian walnut, J. regia L. The walnut caterpillar has been reported on various other tree and shrub species, but food preference tests indicate that the larvae of the insect feed and survive only on species of the Juglandaceae.

Table 1.--Seasonal history of the walnut caterpillar and its parasites in Pope County, Illinois. Based on median emergence dates determined from weather records for a 5-year period 1973 through 1977 in Pope County, Illinois.



Plants used in food preference experiments are shown in table 2.

Table 2.--Plant species used to determine if walnut caterpillar larvae will feed on any plant other than species of Juglandaceae

Common name	Plant species
Apple	Malus sp.
Azalea	Rhododendron sp.
Blackgum	Nyssa sylvatica Marsh.
Black locust	Robinia pseudoacacia L.
Hawthorn	Crataegus sp.
Hazlenut	Corylus americana Walt.
Honey locust	Gleditsia triacanthos L.
Multiflora rose	Rosa multiflora Thunb.
Redbud	Cercis canadensis L.
Red oak	Quercus shumardii Thunb.
Shingle oak	Quercus imbricaria Michx.
White oak	Quercus alba L.
Post oak	Quercus stellata Wang.
Sassafrass	Sassafrass albidum (Nutt.)
Southern catalpa	Catalpa bignonioides Walt.
Sugar maple	Acer saccharum Marsh.
Winged elm	Ulmus alata Michx.
Black willow	Salix nigra Marsh.
Persimmon	Diospyros virginiana L.

Unfed and fed 1st and early 3rd instar larvae did feed on persimmon, but did not survive. Black walnut and shagbark hickory, Carya ovata (Mill.), were used as check plants. In tests to determine food preferences between black walnut and shagbark hickory, the larvae selected the hickory sp. over black walnut at a statistically significant level greater than 0.05%.

Some confusion may occur in food preferences because the walnut caterpillar larvae abandon a tree when the foliage becomes sparse or when it has been defoliated. The larvae will scatter in all directions upon leaving the tree and are apt to ascend any nearby plant. Larvae abandoning defoliated black walnut trees were found on goldenrod, Solidago sp., horseweed, Erigeron canadensis (L.), daisy fleabane, Erigeron annuus (L.), blackberry, Rubus sp., sugar maple, Acer saccharum Marsh., shingle oak, Quercus imbricaria Michx., winged elm, Ulmus alata Michx., and various grasses in the area. Other larvae that had abandoned defoliated black walnut trees were found on sycamore, Platanus occidentalis L., tuliptree, Liriodendron tulipifera L., sweetgum, Liquidambar styraciflua L., and Scotch pine, Pinus sylvestris L. Little or no feeding occurred on any of the trees, weeds, or grasses on which the larvae were found. All but 1 larva had abandoned the plants listed above within 24 hours.

Larval feeding habits vary with the instar. Upon eclosion 1st instar larvae move to the upper surface of the leaflet on which the egg mass is located and devour the surface tissues giving the leaflet a skeletonized appearance. After feeding on the upper leaflet surface the larvae expand their feeding activities to nearby leaflets, and then feed on either surface. The amount of feeding by 1st instar larvae on the lower surface of the leaflet after initially feeding on the upper surface is probably dependent upon the pubescence of the leaflet.

Second instar larvae feed from the edge of the leaflet and devour the entire leaflet except the larger veins. Later they leave only the main vein. Third instar larvae leave the main vein at first, but later leave only a petiolar stub as do the 4th and 5th instars.

Four Tachinidae and 4 Ichneumonidae parasitize the walnut caterpillar larvae. The parasites and the walnut caterpillar life stage from which they were recovered are shown in table 3.

Insects found feeding on walnut caterpillar larvae were identified as the hemipterans Podisus maculiventris (Say)[1], Arilus cristatus (L.)[2], the hymenopteran Vespula maculifrons (Buysson)[3], and unidentified species of Diptera (Asilidae), and unidentified nymphal Orthoptera (Tettigoniidae). Two immature spiders identified as Misumenops sp. and Phiddipus sp.[4] were also found feeding on walnut caterpillar larvae.

Vertebrate predators of walnut caterpillar pupae include the house mouse, Mus musculus L.[5], and the white-footed mouse, Peromyscus leucopus[5]. The caterpillar pupae offered these mice were eaten before corn and soybeans given to the mice at the same time.

[1] Determined by J. McPherson, Southern Illinois University, Carbondale, Illinois.

[2] Determined by D. W. Webb, Faunistics Section, Illinois Natural History Survey, Urbana, Illinois.

[3] Determined by W. E. LaBerge, Faunistics Section, Illinois Natural History Survey, Urbana, Illinois.

[4] Determined by J. E. Unzinger, Faunistics Section, Illinois Natural History Survey, Urbana, Illinois.

[5] Determined by S. P. Havera, Wildlife Research Section, Illinois Natural History Survey, Urbana, Illinois.

Table 3.--Tachinid and ichneumonid parasites emerging from walnut caterpillar cultures in Pope and Champaign Counties, Illinois

Name	Family	Walnut caterpillar stage
Archytas metallicus (R.D.)[1]	Tachinidae	Emerge from caterpillar pupa.
Belbosia semiflava Aldrich[1]	"	"
Lespesia datanarum (Townsend)[1]	"	"
Unidentified		Tachinid larva emerge from caterpillar larva.
Bathylypa paeneferruginea (Vier.)[2]	Ichneumonidae	Emerge from caterpillar pupa.
Tamypelma datanae (Riley)[2]	"	"
Tamypelma fulvicorne (Twns.)[2]	"	"
Unidentified		Emerge from 4th instar caterpillar larva.

[1] Determined by C. W. Sabrosky, U.S.D.A. Systematic Entomology Laboratory, Beltsville, Maryland.

[2] Determined by W. E. LaBerge, Faunistics Section, Illinois Natural History Survey, Urbana, Illinois.

The yellow-billed cuckoo, Coceyzus americana, was observed frequenting infested black walnut trees growing in a bushy area on the margin of a forest. It cannot be verified that the bird fed upon the walnut caterpillar larvae; however, this bird species is a known predator of other hairy caterpillar species.

A microsporidian, Nosema necatrix Kramer[6], was found to be at lethal levels in tissues of 14 out of 20 dead 5th instar larvae. Three of the 6 remaining larvae were dead from bacterial septasemia[6]; the remaining 3 had no pathogenic agent in the tissues. An unidentified virus[6] that causes mummification of the pre-pupal larva and a bacterial agent[6] causing cuticular weakness in pupae were also found.

Predators account for ca. 49% of the larval mortality in a colony of walnut caterpillar while the microsporidian, N. necatrix, accounts for less than 2%. The virus causing mummification of the pre-pupal 5th instar larva accounts for ca. 56% of the mortality in the walnut caterpillar larvae reaching that stage. Pupa diseases account for approximately 60% of the mortality occurring in the pupal stage.

Over a 2 year period tachinids and ichneumonids parasitized ca. 16% of the larvae that survived predation (630 parasites were recovered from 3,938 larvae/pupae).

Chalcid[7] egg parasites emerged from ca. 21% of the eggs collected during a 2 year period (a total of 25,084 eggs were collected). Approximately 18% of these eggs were infertile. The chalcid egg parasite probably is more effective than is indicated in this study. Many of the eggs that were counted as infertile were probably parasitized, but no adult chalcids emerged from such eggs. The eggs were black and did not dry-up or cave-in as unfertilized lepidopterous eggs normally do. Some of the eggs were cut open and dead parasites were found.

[6] Determined by J. Maddox, Section of Economic Entomology, Illinois Natural History Survey, Urbana, Illinois.

[7] Determined by W. E. LaBerge, Faunistics Section, Illinois Natural History Survey, Urbana, Illinois.

An estimated 15% of the walnut caterpillar pupae are eaten by the house and white-footed mouse. The white-footed mouse could be a very important control factor under natural conditions, particularly when walnut caterpillar populations are at epidemic levels. The white-footed mouse is found along the margins of hardwood forests and most naturally occurring black walnut is found in the same areas.

Foliar sprays of malathion 50EC, diazinon 25EC, acephate 75SP, and Bacillus thuringiensis Berliner were applied to 2nd and 4th instar walnut caterpillar larvae. All 4 insecticides were effective; however, at present acephate is the only insecticide of this group approved by USEPA for use on black walnut for walnut caterpillar control. None of the insecticide treatments produced evidence of phytotoxicity on black walnut.

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GROUP DISCUSSION

Weber: Given the high rate of natural control you are getting from parasites and predators, do you think it is really necessary to spray for the walnut caterpillar?

Farris: In the first generation, no; because total number of caterpillars is very low. Around Dixon Springs the second generation begins quite high in numbers. High mortality of larvae has a tendency to prevent foliage damage to the trees, but the highest percentage of mortality does not occur until after the larvae are older. Given 30 large colonies, for example, with 800-900 larvae/colony and a 50 percent mortality rate, 450 surviving larvae on 15-foot tall black walnut trees can hurt those trees. Therefore, it is still sometimes necessary to spray.

Funk: How far do the larvae migrate? When they finish off one tree and are looking for the next one, how far will they move?

Farris: I ran some tests on this. Fourth instar larvae can survive from 176 to 196 hours without food. The time for fifth instar larvae was approximately 120 hours, presumably because of the differences in physiology and the nearness to pupation. Fifth instar larvae also appeared to be diseased whereas fourth instar larvae showed no signs of disease. Their ability to migrate over distances then depends on their state of health and tolerance of starvation.

Smythe: How readily can we translate certain levels of defoliation into a decrease of either nut or wood production?

Farris: You are getting into an area with which I am not familiar. Perhaps someone else can answer that.

Nicholls: There have been several studies on insect defoliation of conifers, something like 170 studies, which showed that defoliation is proportional to the amount of fiber loss. In other words, with 50 percent defoliation of a tree, there is approximately 50 percent fiber loss. I don't know how defoliation relates to deciduous trees but Ken Kessler is planning to do some work on that aspect this summer.

Payne: On pecans, aphid infestation has been related to nut loss, but in the following year's crop. The aphids were affecting mainly return bloom on the Persian walnut in California and on southern pecan in Georgia.

Farris: In 1941 a researcher named Dickson showed that several years of defoliation of black walnut caused the nut kernel to decrease each year. By the end of the third or fourth year of defoliation, little kernel was left.

McPherson: I have two questions. One, is the walnut caterpillar ever trivoltine in southern Illinois?

Farris: It might be possible if weather conditions were right. A very warm spring and a long, warm fall may be suitable for a third generation. I have no proof but I believe that the key to a second generation may be in the amount of light to which newly hatched, first generation larvae are exposed. In May there is probably enough light to trigger the physiological mechanisms for development to proceed. In most years, however, temperatures do not reach the 80° level required for completion of the first generation until sometime into June.

McPherson: I have a second question concerning something I have always been curious about but have never investigated. When these animals migrate from one tree to another, do they migrate in mass or do they just sort of filter over?

Farris: I have observed 3rd, 4th, and 5th instar larvae leaving trees and they just scattered in all directions. At first I thought perhaps light was influencing the direction in which they were traveling but later I found them on the north as well as on the south, east and west sides of trees.

McPherson: Do they all leave the tree at the same time?

Farris: No, they leave over an extended period of time.

A PRELIMINARY REPORT ON THE BIONOMICS OF FULGOROIDEA ON BLACK WALNUT WITH EMPHASIS ON ANORMENIS SEPTENTRIONALIS (SPINOLA) (HOMOPTERA)

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ABSTRACT:--Preliminary findings from a study of the bionomics of Fulgoroidea occurring on black walnut are presented, including a generalized life cycle for Anormenis septentrionalis.

Nixon and McPherson (1977) reported collecting 15 fulgoroid species on black walnut in southern Illinois, 11 of which were noted feeding (Table 1). However, the impact of these species on walnut was not determined. The purpose of the present study is to determine if the above-mentioned fulgoroids are reproducing on black walnut, or are incidental feeders.

Table 1.--A list of the Fulgoroids collected from black walnut trees in southern Illinois (Nixon 1976)

Family/ species	Feeding observations
Cixiidae	
Cixius sp.	
Haplaxius pictifrons (Stal)	
Oliarus sp.	
Delphacidae	
Liburniella ornata (Stal)	X
Derbidae	
Anotia bonnetti Kirby	X
Apache degeerii (Kirby)	X
Cedusa kedusa McAtee	X
Syntames uhleri (Ball)	X
Flatidae	
Anormenis septentrionalis (Spinola)	X
Metcalfa pruinosa (Say)	X
Ormenoides venusta (Melichar)	X
Acanaloniidae	
Acanalonia bivittata (Say)	X
Acanalonia conica (Say)	X
Issidae	
Thionia bullata (Say)	
Thionia simplex (Germar)	X

During 1976, 1977, and spring 1978, collection trips were made primarily to the following walnut plantations in southern Illinois: U.S. Forest Service Tree Improvement Center (T9S R2W S25), Indian Creek Walnut Plantation (T10S R1W S25), and a plantation located near the Swine Center on the SIU-C campus (T9S R1W S31). Other plantations visited included the Union County Tree Farm Walnut Plantation (T12S R2W S8) and a private plantation in Okawville (T1S R5W S13). More complete descriptions of these plantations are given by Nixon and McPherson (1977).

Fulgoroids collected as adults, thus far, include: Liburniella ornata (Stal), Anormenis septentrionalis (Spinola), Metcalfa pruinosa (Say), Ormenoides venusta (Melichar), Cedusa kedusa McAtee, and Acanalonia bivittata (Say). Only 2 species, M. pruinosa and A. septentrionalis have also been collected as immatures, suggesting that the remaining 4 species are incidental feeders.

M. pruinosa appears to be univoltine. Nymphs have been collected on black walnut from 9 to 19 July, adults from 5 to 18 September. Eggs have not been found, but probably represent the overwintering stage. Data from other southern Illinois host plants are more complete and also indicate that this species is univoltine.

A. septentrionalis has proven to be the most common fulgoroid on black walnut in southern Illinois and has been found to breed on this host plant as well as others. The rest of this report concentrates on this species.

A. septentrionalis occurs over much of the eastern U.S. (Metcalf 1923, Van Duzee 1923, Swain 1948). It has been collected in Connecticut, New York, New Jersey, Maryland, District of Columbia, Pennsylvania, Virginia, North Carolina, South Carolina, Georgia, Florida, Mississippi, Tennessee, Ohio, Indiana, Illinois, Iowa, Kansas and Arizona (see Metcalf 1957) and is common throughout its range (Southwick 1892, Swain 1948). Walden (1922) noted high populations in 1921 in Connecticut.

A. septentrionalis has been noted feeding on shrubs and woody vines (Swain 1948), especially on shoots and midribs of leaves (Comstock 1940), and collected from over 30 species of plants (Table 2). It has been implicated in foliage damage to Cornus asperifolia (of authors not Michaux) (= Cornus drummondi Meyer) (Swezey 1903) and was thought to be involved in the transmission of blueberry stunt disease until this was disproven by Tomlinson et al. (1950).

A. septentrionalis breeds on many shrubs and vines (Dozier 1928). The eggs have been found in several woody plants (Table 3) and the ovipositional damage has been described (Hoffmann 1942). Laboratory reared animals during the present study have laid eggs in the fleshy tissue of snap beans (Phaseolus vulgaris L.).

The first report of an association of A. septentrionalis with black walnut in southern Illinois was by Nixon and McPherson (1977) who found eggs, nymphs and adults on this host plant. During the course of the present study, black walnut twigs containing A. septentrionalis eggs have been found at the following southern Illinois locations: The La Rue-Pine Hills Ecological Area, Thompson Woods on the SIU-C campus, a private walnut plantation in Okawville, and the U.S. Forest Service Tree Improvement Center, SIU-C.

The following generalized life cycle information for A. septentrionalis includes data from black walnut and other host plants (see SWW/JEM, Table 2). The eggs are laid in the fall (earliest collection date, 5 September), overwinter, and hatch in spring. They are inserted into twig tissue in one or more rows. A typical row has a zipper-like appearance with the eggs forming a ridge on the surface of the twig (Figure 1). A search for eggs in black walnut twigs at the Tree Improvement Center during fall 1977 resulted in 316 in 16 different twigs (mean number of eggs per cluster $\pm$ 1 S.E. = 19.75 $\pm$ 2.44). The eggs were found within localized areas of the plantation (Figure 2).

First instars (Figure 3A) have been found from 23 May to 1 June; second instars (Figure 3B), 25 May to 6 June; third instars (Figure 3C), 25 May to 6 June; fourth instars (Figure 3D), 26 May to 30 June; fifth instars (Figure 3E), 8 June to 29 July; and adults (Figure 4), 23 June to 28 October.

ACKNOWLEDGMENTS

We wish to thank D. T. Funk and B. C. Weber, Forestry Sciences Laboratory, North Central Forest Experiment Station, U.S.D.A., Carbondale, Illinois, for their willing assistance during this study.

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Table 3.--A list of the oviposition sites of Anormenis septentrionalis

Common name	Scientific name	References
Hickory	Carya sp.	Dozier 1928
Black walnut	Juglans nigra L.	Nixon & McPherson 1977 SWW/JEM[1]
Sweetgum	Liquidambar styraciflua L.	Dozier 1928
Black cherry	Prunus serotina Ehrhart	SWW/JEM
Oak	Quercus sp.	Dozier 1928
American elm	Ulmus americana L.	Hoffmann 1942
Redbud	Cercis canadensis L.	SWW/JEM

[1] SWW/JEM = this study

Table 2.--A list of the plant associations of Anormenis septentrionalis

Common name	Scientific name	Stage[1]	Feeding	References
Maple	Acer sp.			Heaton 1934
Silver maple	Acer saccharinum L.	A	X	SWW/JEM[2]
Black alder	Alnus glutinosa (L.)		X	Dozier 1928
			X	Osborn 1938
Crossvine	Bignonia capreolata L.		X	Dozier 1928
Pignut hickory	Carya glabra (Miller)	A	X	SWW/JEM
Pecan	Carya illinoensis (Wangenheim)		X	Dozier 1928
Climbing bittersweet	Celastrus scandens L.	N	X	Swezey 1903
			X	Dozier 1928
			X	Osborn 1938
Redbud	Cercis canadensis L.	A	X	SWW/JEM
Roughleaf dogwood	Cornus drummondi Meyer	N	X	Swezey 1903
Flowering dogwood	Cornus florida L.	A	X	SWW/JEM
Dogwood	Cornus sp.		X	Dozier 1928
			X	Osborn 1938
Hawthorn	Crataegus sp.	N	X	Swezey 1903
			X	Dozier 1928
			X	Osborn 1938
American beech	Fagus grandifolia Ehrhart			SWW/JEM
Ash	Fraxinus sp.			Heaton 1934
Honey locust	Gleditsia triacanthos L.			Heaton 1934
Black walnut	Juglans nigra L.	N	X	Nixon & McPherson 1977
		A	X	SWW/JEM
Sweetgum	Liquidambar styraciflua L.	A	X	SWW/JEM
				Dozier 1928
Yellow sweet clover	Melilotus officinalis (L.)	N	X	SWW/JEM
Red mulberry	Morus rubra L.	N	X	SWW/JEM
Hophornbeam	Ostrya virginiana (Miller)	A	X	SWW/JEM
Pokeweed	Phytolacca americana L.			Dozier 1920
American sycamore	Platanus occidentalis L.			Heaton 1934
				SWW/JEM
Black cherry	Prunus serotina Ehrhart	N	X	SWW/JEM
		A	X	SWW/JEM
Plum	Prunus sp.	N	X	Swezey 1903
			X	Dozier 1928
			X	Osborn 1938
Red oak	Quercus rubra L.	N	X	Swezey 1903
			X	Dozier 1928
			X	Osborn 1938
Willow	Salix sp.			Heaton 1934
American elm	Ulmus americana L.			Gibson 1973
Slippery elm	Ulmus rubra Muhlenberg	N	X	SWW/JEM
		A	X	SWW/JEM
Elm	Ulmus sp.			Heaton 1934
Blueberry	Vaccinium sp.	A	X	Tomlinson et al. 1950
Verbisina	Verbisina			SWW/JEM
Grape	Vitis sp.	N	X	Swezey 1903
				Wirtner 1905
			X	Dozier 1928
				Heaton 1934
			X	Osborn 1938
				Comstock 1940
Prickly ash	Xanthoxylum americanum Miller	N	X	Swezey 1903
			X	Dozier 1928
			X	Osborn 1938
Corn	Zea mays L.			Heaton 1934

[1] A = Adult, N = Nymph
[2] SWW/JEM = this study

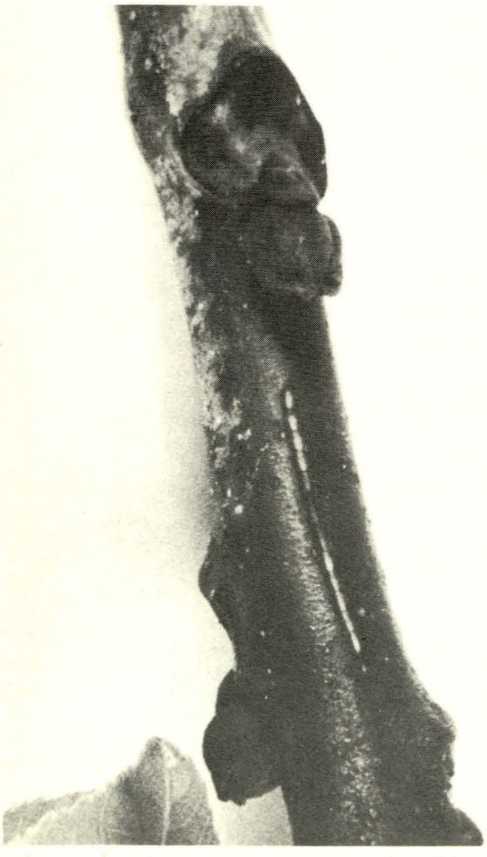

Figure 1.--Eggs of A. septentrionalis inserted in a black walnut twig.

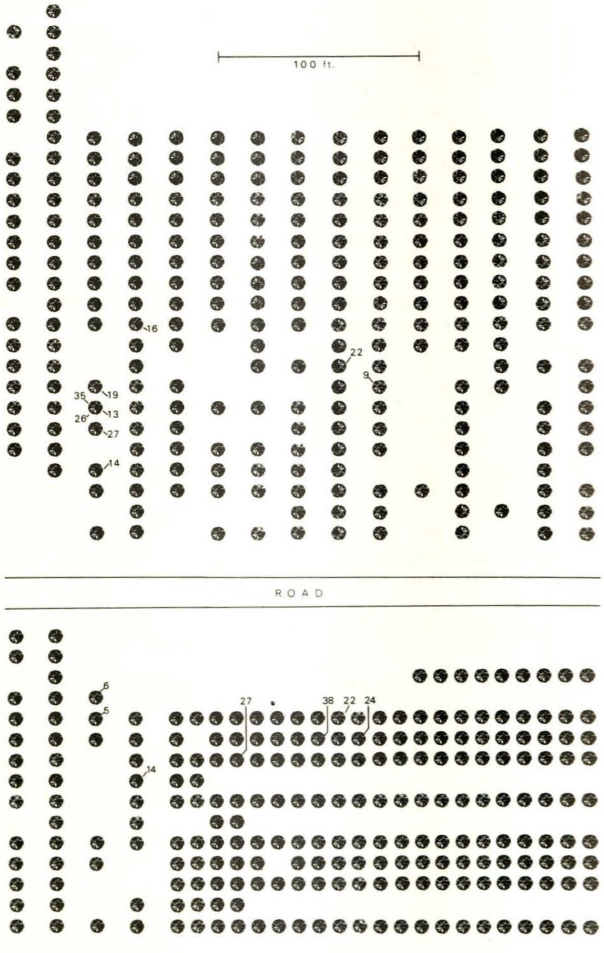

Figure 2.--Distribution of A. septentrionalis ovipositional sites at the U.S. Forest Service Tree Improvement Center Walnut Plantation, SIU-C. Numbers indicate the number of eggs in a twig.

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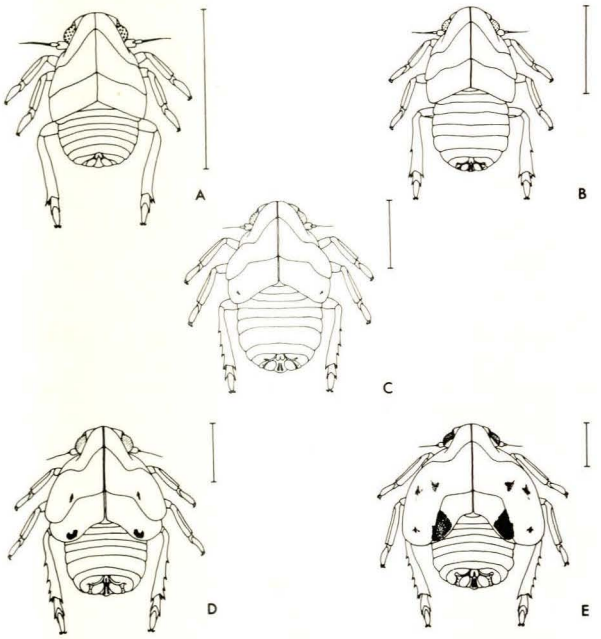

Figure 3.--Immature stages of A. septentrionalis. A, first instar; B, second instar; C, third instar; D, fourth instar; E, fifth instar. Line equals 1.0 mm.

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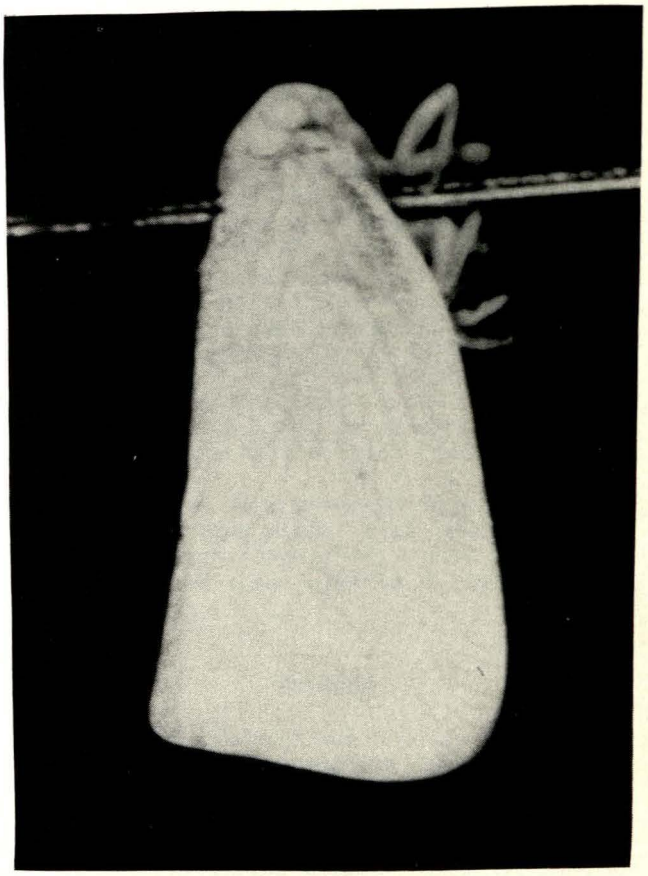

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GROUP DISCUSSION

Kuntz: Have you determined that these chocolate brown lesions, either on the leaves or the twigs, are a result of the activities of these insects?

S. Wilson: No, I haven't to date. We have tagged twigs in the field in which there have been eggs, and we will follow them this year. Of all the ones that were tagged last year only one twig failed to leaf out and there may have been other causes.

Schlesinger: Do they lay their eggs in last year's wood?

Wilson: No, I have observed eggs only in the current year's growth. Oviposition damage from previous years is evident on the twigs, but I've found fresh eggs on the current year's growth only.

THE BUTTERNUT CURCULIO ON SOME HYBRID WALNUTS IN MICHIGAN

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ABSTRACT.--Susceptibility of several species and hybrids of walnuts to attack by the butternut curculio is given and injury classes are proposed. Progeny from a J. nigra X J. sieboldiana cross were most susceptible to attack.

The butternut curculio, Conotrachelus juglandis LeConte, attacks native and exotic species of natural and planted Juglans in eastern North America. The larvae and adult weevils injure or destroy the nuts, young stems, and leaves of their hosts, and thus curtail nut production and modify tree growth and form. The life history of this insect has been studied in Connecticut (Britton and Kirk 1912) and in West Virginia (Brooks 1922). Its range, however, extends throughout Eastern North America--contiguous with the natural range of butternut, its native host.

In 1975, we found the butternut curculio attacking the shoots of several hybrid Juglans in a research planting at the Kellogg Forest near Augusta, Michigan. The apparent wide range of attacks suggested a wide range of susceptibility. Some of these trees may eventually be used for seed selection due to their superior growth or nut production, so we undertook this study to determine: (1) the insect's life history in Michigan, (2) the degree of susceptibility of walnut trees to weevil attack, and (3) the degree of feeding damage impact.

STUDY AREA

The study area was a putative hybrid walnut plantation (compartment 20A) of the Kellogg Forest, Kalamazoo County, Augusta, Michigan. The plantation was established in 1968 and consisted of open-pollinated progeny of the following species and hybrids: Juglans nigra (black walnut), J. cinerea (butternut), J. regia (English walnut), J. sieboldiana (Japanese walnut), J. nigra X J. sieboldiana, J. regia X J. nigra, and J. sieboldiana X J. cinerea. The J. nigra was planted in part as a buffer along two edges of the plantation. Also, a large J. nigra provenance planting was adjacent to the hybrid plantation.

The trees were arranged in a randomized block design with eight replicates comprising 26 seed sources (Funk 1971). Each block consisted of five trees planted 10 feet apart in a row.

METHODS

The life history was studied in 1975 and 1976 from field observations and branch samples collected each week throughout warm weather (Corneil and Wilson 1978). Host susceptibility was determined by evaluating the degree of larval attacks and adult feeding on samples of each hybrid. In 1975 and 1976, each tree in the planting was scored attacked or not attacked and the percentage calculated for each replicate and each hybrid. In 1976, an injury index was developed for each hybrid to get a better estimate of the degree of attack. The index was based on the degree of attack on each tree and the percentage of trees attacked (Wilson et al. 1978). Indices between hybrids were contrasted using Scheffe's method of multiple comparisons for significant (0.05 level) differences.

LIFE HISTORY AND HABITS

Conotrachelus juglandis is univoltine in Michigan. The adult is the overwintering stage and it may live for a full year or longer.

In Michigan oviposition begins about the second week of May and continues until early August. The female weevil oviposits one egg in each niche she chews in the young shoots. Each niche is flanked on three sides by a

crescent-shaped slit, which prevents the egg from being crushed by rapidly growing plant tissue (Porter 1932). A flap of tissue usually conceals the egg, and frass pellets sometimes plug the niche opening.

First-instar larvae appear in mid May about 6 to 12 days after oviposition, depending on the temperature (Britton and Kirk 1912). Each small larva bores into the pith and feeds up or down the stem or into the bases of the leaf petioles. The pith is soft and green at this time. As the larva grows it makes a larger and longer tunnel and is restricted only by the pith diameter of the shoot and petioles. Thus, oldest larvae are nearly always toward the shoot base where the pith diameter is largest, and youngest larvae are near the tip. Two or more larvae occupying the same shoot are able to completely bore out the center of the shoot. Larvae running out of food and reaching the base of the new shoot usually feed into the cambium and girdle the shoot there, and this is the major cause of shoot wilting and death. Partially hollowed-out shoots that do not break off usually survive.

During the larval growth period the egg-niche opening becomes the entrance to the larval tunnel and an ejection hole for frass. An active larval gallery has frass at the entrance and a darkened area of tissue encircling the opening.

There are five larval instars and the entire larval period lasts 4 to 6 weeks. When fully developed, the larvae exit through the tunnel opening and drop to the ground, usually during the early morning hours before heat of the day (Brooks 1922). Larvae begin dropping about mid June in Michigan and all have dropped by late August. The larvae then burrow into the soil as deep as 3 inches and construct small earthen pupal cells.

Pupation occurs 7 to 10 days after the larva enters the soil, and the pupal period lasts between 15 and 20 days. In Michigan the mean period from the time the larva enters the soil until the adults emerge is 27 $\pm$ 3 days. First adults appear in the second or third week in July and the last adults have emerged by mid September. Young adults fly to the host trees and feed on the soft tissues of the shoot tips, leaf rachis, and on the leaflets. Adults generally feed at night and rest on the foliage or hide during the day.

In autumn the adults drop to the ground, crawl beneath the litter, and burrow into the soil beneath the tree's canopy where they overwinter. In May they emerge, return to the tree, seek mates, and the females soon begin to oviposit. Adults feed on the soft, new shoot and leaf tissues throughout the summer and die in late summer or early autumn.

HOST SUSCEPTIBILITY

In general trees with Japanese walnut parentage were attacked the most by the weevil larvae; from 90 to 100 percent of the progeny were attacked in 1975 and 1976 on these hosts (table 1). Conversely black walnut was the least attacked--17 percent or less when planted among the hybrids. The adjacent walnut stand, which was a regional provenance planting of pure *J. nigra*, was not attacked.

The progeny from the *J. nigra* X *J. sieboldiana* parent sustained significantly higher injury and was 10 times more susceptible than black walnut (table 1). Progeny from *J. sieboldiana* were the second most injured, and those of *J. regia* X *J. nigra* and *J. sieboldiana* X *J. cinerea* were third. Both the *J. sieboldiana* and the *J. nigra* X *J. sieboldiana* progeny were 100 percent attacked by the weevil, yet the latter had almost twice as much injury. *J. regia* and *J. cinerea* were injured about the same as black walnut and these three together were ranked the lowest in susceptibiltiy. *J. regia*, however, had a much higher percentage of trees attacked than the others--a range of 71 to 95 percent, compared to 42 to 48 percent for *J. cinerea* and 15 to 17 percent for *J. nigra*.

Adult feeding ranked almost parallel to the larval feeding intensity but the differences between them were far less. The *J. nigra* X *J. sieboldiana* progeny had more than four times as many feeding wounds and *J. sieboldiana* had two times as many feeding wounds as *J. nigra*, *J. cinerea*, or *J. regia*.

DISCUSSION

The life history and habits of *C. juglandis* in Michigan are similar to those recorded for Connecticut (Britton and Kirk 1912) and West Virginia (Brooks 1922), except the life cycle begins a few weeks earlier and ends a few weeks later in Michigan.

Table 1.--Susceptibility and injury to various walnut progeny by the butternut curculio, 1975-1976

Juglans - Female Parent (Male open-pollinated)	Seed Sources (No.)	Progeny Trees (No.) 1976	Tree Mean Height (m) 1976	Trees Attacked (%) 1975	Trees Attacked (%) 1976	Mean Injury Index (I) 1976[1/]
J. nigra X J. sieboldiana	1	20	4.4	100	100	24.0 a
J. sieboldiana	1	14	5.6	100	100	14.3 b
J. sieboldiana X J. cinerea	7	243	4.8	90	90	8.9 c
J. regia X J. nigra	4	57	2.7	88	81	7.8 c
J. regia	1	19	2.1	95	71	4.3 d
J. cinerea	2	55	4.7	42	48	2.8 d
J. nigra (within stand)	10	41	4.8	15	17	2.3 d
J. nigra (adjacent stand)	10	160	4.9	0	0	0 e

[1/] Indices followed by the same letter are not significantly different at the 0.05 level.

The main injury from C. juglandis to walnuts is from larvae tunneling in the pith and girdling the base of the new shoots. Tunneling weakens the shoot so growth is slowed or so they eventually break from wind or snow. Girdling kills the shoot by severing the cambium, and because most girdling occurs near the base of the new shoot, most or all of the season's growth is lost.

Adult injury occurs mostly during spring feeding when the shoots are small and succulent. Then feeding niches may cut through half of the shoot's diameter and cause it to wilt and die. After mid-June damage is less serious because the shoots are larger. Fall feeding following new adult emergence causes numerous feeding wounds along the shoot, but these scar and callous usually without injuring growth or form. Adults also heavily skeletonize the leaflets. Feeding wounds on leaf petioles in the fall kill an occasional leaf but natural leaf fall occurs shortly thereafter anyway.

Britton and Kirk (1912) ranked several species of Juglans attacked by the butternut curculio in the following preferred order: J. cordiformis, J. sieboldiana, J. cinerea, J. regia, J. nigra, and J. mandschurica (manchurian walnut). Brooks (1922) noted that J. cathayensis (Cathay walnut) was sometimes seriously injured by this weevil and was perhaps about as susceptible as the Japanese walnuts.

Host preference ranked similarly in our study excluding progeny from J. mandschurica and J. cathayensis, which were not available for comparison. Progeny with Japanese walnut parentage were highly preferred over the other exotic and native hosts. Black walnut appeared to have little or no effect on the susceptibility to attack when crossed with other walnuts, whereas butternut seemed to decrease susceptibility when crossed with Japanese walnuts.

Although English walnut ranked about the same as butternut and black walnut, it still may be slightly more susceptible than expected. English walnut trees grew poorly in Michigan and each year their shoot tips were killed back by late frost. Those that had not died in the study plots were short, deformed, and bushy. Presumably, few available shoots were available for weevil attack after each spring frost. An indication that they might be more susceptible is reflected perhaps in the J. regia X J. nigra cross, which had significantly higher injury than J. regia or J. nigra alone. The progeny from this parent had less frost injury each spring than the English walnuts and thus more shoots available for attack. Because J. nigra is barely susceptible and does not seem to contribute much to susceptibility in other crosses, the J. regia component in this cross most likely contributed the additional susceptibility. This may be important for future crosses or further south of the latitude of Michigan where English walnut might be planted.

Black walnut either lacks a substance that attracts the weevil or contains a substance that repels them. Extensive observations in the walnut provenance planting, which was adjacent to the hybrid planting,

indicated the adult weevils only nibbled a small amount on the trees. Oviposition was extremely rare and no larval tunnels were found, confirming black walnut as an extremely poor host (Britton and Kirk (1912) and Porter (1932) have also reported that black walnut is seldom attacked by C. juglandis).

Butternut was not much more susceptible to injury by the weevil than black walnut, though there was a slightly higher percentage of trees attacked. Native butternut is the weevil's principal host in natural situations, so perhaps natural selection has favored this tree's resistance.

The degree of shoot injury observed on the various hosts in this study suggests four injury classes J. nigra, J. cinerea, and J. regia are in the Very Low Class. Such trees have no more than 0.5 weevil attacks per shoot. Sparse and widely scattered shoot and leaf flagging (wilting) occurs on them and damage at most is slightly cosmetic. J. sieboldiana X J. cinerea and J. regia X J. nigra are in the Low Class and have approximately 0.5 to 1.0 attacks per shoot. These trees show scattered shoot flagging and the few trees that are killed have multiple attacks on the same shoot. J. sieboldiana are in the Moderate Class and have 1 to 3 attacks per shoot. Shoot and leaf flagging readily occurs throughout the tree's crown but is widely scattered. Some lateral and an occasional leader shoot are killed back at this density. Tree form is affected mostly where attacks on leaders occurs two or more years in a row. J. nigra X J. sieboldiana are in the High Class. These have more than three attacks per shoot, and many shoots are hollowed out for more than 30 percent of their length. Heavy wilting occurs to shoot tips and leaves. Many shoots die--less than half of the injured shoots recover the year following attack. Trees with the amount of injury in the High Class category will usually warrant suppression measures.

No attempt has yet been made to suppress the butternut curculio. However, its life history is similar to the black walnut curculio, C. retentus (Say), so similar suppression measures are plausible. Both weevils appear to be suppressable in the adult stage--either while feeding in late summer and autumn following emergence or in the spring after overwintering. Jaynes (1969) recognized fall spraying as a potential time for C. retentus control. The adults feed for more than a month in the fall so there is a good chance they will eat or contact any persistent pesticide. Gibson and Kearby (1975) obtained fair suppression of C. retentus adults during the beginning of feeding and oviposition. Similar techniques should be tried on the butternut curculio.

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GROUP DISCUSSION

Weber: I would like Dave Funk to comment on the cross between Juglans cordiformis and nigra as to its importance as a hybrid tree.

Funk: I think this is perhaps the most promising cross we have. I fooled around with walnut hybrids quite a bit and am rather well discouraged with the whole program, but the cordiformis X nigra cross is rather vigorous and might be a pretty good dual-purpose tree.

L. Wilson: I would like to mention that the people in Connecticut (Britton and Kirk) rank their trees almost identically to some of the crosses in our study. Pure cordiformis is highly preferred by the butternut curculio. In our study my only question was that nigra did not seem to knock down any of the

resistance whereas cinerea did knock back the resistance to some extent. That's the only thing I could see from the data that made sense to me. As a geneticist, maybe you see something different.

Funk: I think that is a fairly limited sample of what the species might produce. We're looking at individual parents.

Wilson: I realize that but at least the parallels were identical. They were in the same order of preference with almost no differences. If there were, they were just reversed by number but not be significance. J. cordiformis seems to be the most susceptible species that we've tested. Mandshurica was brought in, too, as a fairly susceptible species.

THE LIFE HISTORIES OF ACROBASIS JUGLANDIS AND A. DEMOTELLA ON BLACK WALNUT IN MICHIGAN

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ABSTRACT.--Describes the life histories of two walnut pests: one a shoot borer and the other primarily a defoliator. Some control recommendations are proposed.

At least two pyralid moths, Acrobasis juglandis (LeBaron) and A. demotella Grote are injurious to young black walnut, Juglans nigra L., trees in Michigan. A. juglandis, the pecan leaf casebearer, is well known in the southern United States as a severe defoliator of pecans (Bissel 1942, Gill 1917, Nickels 1951), but except for studies in Missouri (Kearby 1975) little is known of its biology in the northern United States on walnut. A. demotella, the walnut shoot moth, has had less attention (Hulst 1890, Neunzig 1972, Kearby 1975) until recently when Kearby (1978) reported on its biology and injury in Missouri. In 1975, we began a study on the life histories of both species in Michigan.

METHODS AND MATERIALS

This study was conducted during 1975 and 1976, in a 6-acre black walnut plantation in Branch County, and in a 20-acre mixed woodlot and old field in Clinton County, Michigan. Additional data were collected from walnut plantings in Shiawassee, Clare, Livingston, and Kalamazoo Counties. Sample trees were less than 15 cm d.b.h., 10-15 years old, and under 6 m tall.

Insect specimens were collected one or more times each week. Some were fixed in KAA and then transferred to 80 percent ethanol for head capsule measurements. Several larvae were reared in the laboratory on potted walnut seedlings. Adults were reared from late-stage larvae in Deitz globes covered with fine-mesh cloth. Adults were captured with light traps after emergence in the field.

LIFE HISTORY AND HABITS

Both A. juglandis and A. demotella are univoltine in Michigan (fig. 1). Each species undergoes five larval stages. The larvae are difficult to distinguish in the first three instars as their size, head capsule measurements, and setal patterns are similar. In the fourth and fifth instars however, A. demotella is larger than A. juglandis as follows:

Species	In-star	No. head capsules	Mean width (mm)	Range (mm)
A. juglandis	IV	14	0.775	0.644 - 0.993
	V	24	1.214	1.043 - 1.373
A. demotella	IV	8	0.981	0.948 - 1.098
	V	20	1.448	1.299 - 1.610

Martinat (1978) and Kearby (1978) give further details on separating these species by morphology and behavior.

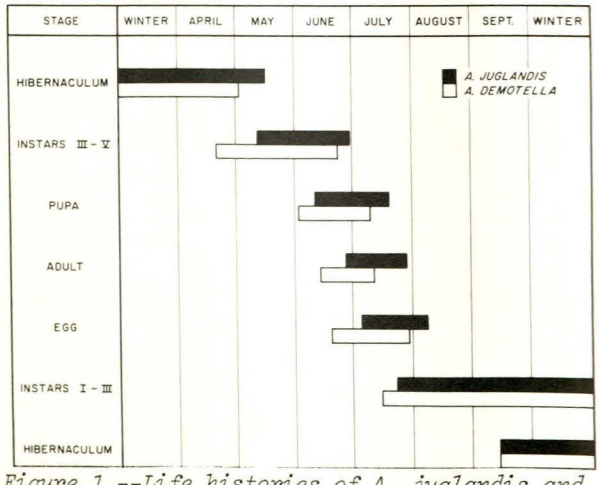

Figure 1.--Life histories of A. juglandis and A. demotella on black walnut in Michigan.

Egg Stage and Larval Instars I-III of A. juglandis and A. demotella

Oviposition starts in the latter half of June for A. demotella and early July for A. juglandis (fig. 1). Eggs are deposited singly on the underside of the leaves, usually next to the midrib on the basal half of the leaflet. Turner et al. (1978) and Leiby (1925) found up to 30 eggs in a single leaflet on pecan. No leaflet was found with more than two eggs in Michigan; 40 percent of the egg-bearing leaflets had two eggs, 60 percent had one.

The eggs fit Gill's (1917) description of those of A. juglandis. They are elliptical, ivory white, convex above, and flattened below, with a reticular micro-pattern on the outer surface of the chorion. Vacated eggs are colorless and usually collapsed with a round exit hole at one end. The average size of ten eggs was 0.28 x 0.71 mm. Eggs laid in the lab from field-collected A. demotella adults were similar in appearance and size to those of A. juglandis. The incubation period for lab-oviposited A. demotella eggs averaged 11 days.

Larvae appear in late July. First instars of both species are pale reddish brown and about 0.8 mm long. Shortly after eclosion they wander a short distance from the egg shell and begin constructing a sinuous trumpet-shaped case of frass on a silken framework. The larvae from the first to the third instars feed on the lower epidermis, skeletionizing the leaflet in the vicinity of the case. When foliage starts to discolor in mid-to late September, the third instar larvae vacate the cases and move to the nearest shoots and construct oval brown hibernacula that are approximately 1 mm long. These are usually concealed at the base of the buds. There the larvae overwinter.

Late Larval Instars, Pupae, and Adults of A. juglandis

Third instar larvae of A. juglandis emerge from their hibernacula in the spring, begin feeding at the base of the terminal bud, and conceal themselves beneath loose, silken, frass-coated webbing. Emergence varies with differences in spring temperature. Active larvae were first observed on May 12, 1975, and on April 30, 1976. The larvae continue to feed at the base of the bud for several weeks and throughout third instar development. Some buds are killed, but most expand and foliate normally.

The fourth instar moves to the expanding leaf and constructs a silken frass-coated case attached to the rachis, usually near the terminal pair of leaflets. The case is enlarged as the larva grows and adjacent leaflets are pulled together, fastened with silk, and fed upon. The last instar larvae feed on the bases of the leaflets and rarely leave their cases. Fully mature larvae seal the ends of the cases and await pupation.

The first pupae appear near mid-June; the entire pupal period may last until mid-July. A. juglandis pupae reared in the laboratory averaged 16.3 (12-24) days to develop to adults.

Adults emerge from the cases in late June. Adults were observed in Branch County between June 26 and July 18--the peak occurred from July 11-14. In Shiawassee County (80 miles further north) they were seen from June 25 to July 27 with the peak between July 14-16.

Late Larval Instars, Pupae, and Adults of A. demotella

Third instar larvae of A. demotella emerge from their hibernacula in late April or early May depending on the weather. The larvae feed at the base of the bud, similar to those of A. juglandis, concealed in a silken web. The habits are sufficiently different, however, to distinguish them at this stage (Kearby 1978). As the larvae reach the fourth instar they tunnel into the newly developing shoots. Most enter the shoot in the axils between the shoot and the leaf petiole. Larval tunnels may reach 45 cm long; their openings are concealed with frass and silk. Both fourth and fifth instars tunnel in the shoot. Hollowed-out shoots invariably wilt and die.

Near the end of May or beginning of June the last instar larvae start vacating the shoots, drop to the ground, and burrow a short distance into the soil beneath the tree. There, they form a pupal cell, and await pupation. First pupae appear in early June, and the pupal period lasts about 16 days. Adults emerge after mid-June. Trapped adults were collected in Branch County from June 23 to July 15 with the peak between June 26-29; and in Shiawassee County from June 20 to July 28, with the peak around June 25-26.

DISCUSSION

The life histories of A. juglandis and A. demotella are similar but most stages of A.

demotella occur 1-2 weeks earlier in Michigan. Both have similar habits in the early larval instars, but considerably different habits in the last two instars. Their closely parallel life histories and similar habits suggest that they probably were sibling species. Initial geographic separation followed by subsequent overlap of ranges for example, could have led to late instar competition and divergence in habits. Studies made on other species of Acrobasis (Balduf 1966, Walley 1954, Wilson 1970, Pierce and Appleby 1973) suggests that this may have occurred many times in the genus. Wilson (1970) for example, stated that A. comptoniella and A. rubifasciella are nearly morphologically identical in the adult stage, but have distinct behavioral differences in the larval stages--a classic case of sibling species.

The highly divergent habits of these insects in the last-larval stages has brought about two distinct types of injury to the tree: shoot destruction and defoliation. Because A. demotella is a shoot borer, and because just one larva can kill a shoot or leader and cause a crooked tree, it is the more serious threat to walnut in Michigan. It is also the most destructive shoot borer in Missouri (Kearby 1978). A. juglandis normally causes only a small amount of growth loss or injury from its defoliation. Populations of A. juglandis would have to be several times more numerous to cause damage equal to A. demotella. Our light-trap catches of adults produced five A. demotella to one A. juglandis during both years of study, suggesting A. juglandis may be poor competitor in the early stages. It ecloses later in the summer and also appears later in the spring and thus may find its niche occupied by A. demotella.

Actual degree of injury was difficult to assess in this study because neither insect population was very high. Populations of both increased somewhat in 1976 following an exceptionally mild winter in 1975 which probably lowered overwintering mortality. A. demotella, however, is potentially destructive if it affects the form-phase of walnut development. When buds were killed and shoots hollowed out, lateral buds grew and caused crooked and multiple branches. Suppression most likely will be needed for A. demotella when populations build up.

Martinat (1978) tested three systemic pesticides against both species. He tried aldicarb, carbofuran, and disulfoton granular applications in late April 1976. Mortality, however, was not sufficient to warrant recommendations, and he felt better suppression might have been obtained if applied earlier.

McKeague and Simmons (1978) tested acephate and methoxychlor as single bud sprays and whole tree sprays. Acephate was consistently 10 to 20 percent more effective than methoxychlor.

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GROUP DISCUSSION

Weber: Bill Kearby finds that even with the first 3 instars he can tell the difference between the two species--juglangis and demotella--by means of their habits. According to Kearby, Acrobasis juglandis never goes into the bud. It chews on the outside of the expanding leaf, whereas demotella bores into the bud immediately after it comes out of its hibernaculum.

Another comment concerning Acrobasis is that we are studying the genetic resistance of black walnut to Acrobasis attack. Several seed sources from the Midwest planted as a seed orchard are being tested. Results indicate that the average infestation rate is high, ranging from 20 percent in 1977 and 33 percent in 1978, and that there are seed source differences.

McPherson: Louie, are you sure you only have two species in Michigan?

Wilson: I recently heard that there is a third species in Wisconsin but I don't know anything about it.

McPherson: In southern Illinois we have found 3 or 4 species. I wonder if some of the foul-up in data could be in mixing species?

Wilson: That is a possibility. The third species in Wisconsin was found on nursery trees. I don't know its name but it was determined to be different from juglandis or demotella.

Payne: We've been told that the insect we collect from pecan is the pecan nut casebearer, Acrobasis nuxvorella. We don't even use juglandis anymore. You made a comment earlier that you wondered if the species we had in the South is different. Maybe the taxonomists wonder, too, but we have to rely on them for our identification.

Wilson: It bothers me when the same species is reported all the way from Wisconsin to here in southern Illinois.

Payne: A taxonomist in North Carolina named Neunzig has published a monograph on Acrobasis. All the specimens that we have sent to him came back identified as nuxvorella, the pecan nut casebearer. Therefore, we don't know if we have juglandis in Georgia.

Pecan growers in Mexico reported an outbreak of nut casebearer where it supposedly was not distributed. We collected specimens and found not only the nut casebearer, nuxvorella, but also one called the nursery casebearer. This last was a new one which has not been reported from Georgia.

McPherson: Acrobasis latifasciella is another one of the species we have here in southern Illinois.

Wilson: That's the big problem. Taxonomists can't straighten it out by doing all our work for us.

EFFECTS OF INSECTICIDAL AND CULTURAL METHODS TO REDUCE ACROBASIS SPP. AND FROST INJURY ON BLACK WALNUT[1]

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ABSTRACT:--Excessive forking of black walnut saplings was noted in several plantations in Southern Michigan. Acrobasis juglandis (LeBaron) and A. demotella Grote cause forks by feeding on walnut buds and shoots. Two insecticides, acephate and methoxychlor, were tested for effectiveness against these insects. Trials were conducted in the spring and fall. In each case, acephate and methoxychlor caused a significant reduction in both the damage and the number of insects, with acephate consistently 10 to 20% more effective. A single bud spray test conducted in the spring resulted in a greater reduction of Acrobasis damage than did whole tree spraying. Mortality resulting from the fall spray test was 60 to 80%.

Frost also plays a major role in damaging buds and shoots. In 1977, nearly 100% of the terminal buds were killed by the combined action of frost and Acrobasis larvae. As a corrective measure for both problems, pruning was tried. All but one of the new shoots on a damaged branch were removed in early summer. This pruning technique corrected forking effectively. In areas where frost is known to damage black walnut saplings, corrective pruning may be a more reliable method for preventing forking than is spraying an insecticide to control only Acrobasis spp.

Black walnut saplings with an unusually high proportion of killed terminal buds and forked branches were observed in several southern Michigan plantations (Figure 1). Insects, identified as Acrobasis juglandis (LeBaron) and Acrobasis demotella Grote (Lepidoptera: Pyralidae), were found feeding on walnut buds and shoots.

Two insecticides, acephate (Orthene) and methoxychlor, were tested for effectiveness against these insects. Tests were conducted in the spring and fall. During the evaluation of the spring spray test, another type of bud damage was noticed, which was caused by late frost. Since black walnut is growing at the northern limits of its range in Michigan, frost damage is likely to be a continuing problem. A pruning technique was tested for its effectiveness in reducing both insect and frost-caused injury. This paper briefly describes the insects' life history and damage and reports the results of these insecticide and pruning tests.

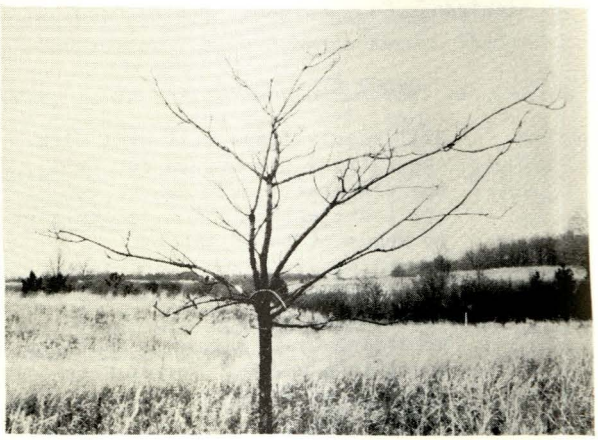

Figure 1.--Black walnut in Michigan with many killed terminal buds and forked branches.

THE INSECT AND ITS DAMAGE

Both Acrobasis juglandis and A. demotella (Lepidoptera: Pyralidae) have been found feeding on walnut in southern Michigan. They damage terminal growth of trees by feeding on expanding buds and shoots in the spring. Several authors have researched the life history of these insect (Gill 1917, Kearby 1975, Martinat 1975, Nickels 1951).

[1] Michigan Agricultural Experiment Station Journal Article No. 8595.

Larvae of both insects overwinter in small inconspicuous cases or hibernaculae on or near the buds (Figure 2). According to Kearby (1965), A. juglandis prefers lateral buds and A. demotella, terminal buds. The spring feeding habits of these two insects are very similar. The larvae emerge when buds burst and feed on the expanding buds. This feeding usually results in the death of the bud. A. juglandis continues to feed on opening buds or at the base of new shoots for several weeks. Some A. demotella larvae move to a partially grown shoot and begin boring into it. These tunneled-out shoots often wilt and die back to the previous year's growth.

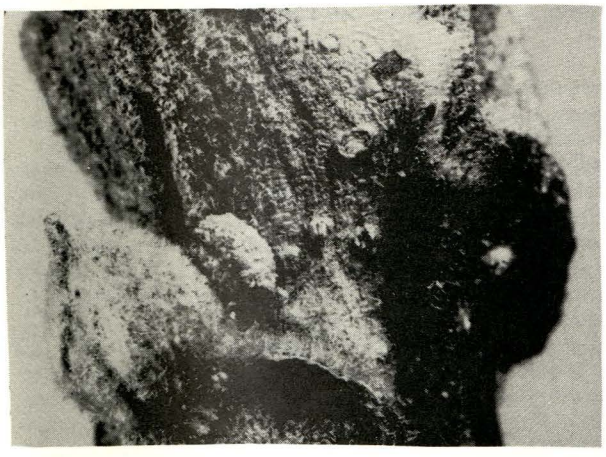

Figure 2.--Hibernacula of Acrobasis juglandis or Acrobasis demotella larvae on a walnut bud.

By early June, in Michigan, most A. demotella have dropped to the ground to pupate. They pupate just beneath the soil surface in an earthen cell (Kearby 1975). A. juglandis larvae have by this time moved from the bases of shoots to the undersides of leaves, where they build a silk and frass tube attached to the rachis (Figure 3). Two leaflets on either side of the case are fastened around it. The larva free-feeds on these and nearby leaflets. In mid June the larva closes the end of the case and pupates inside.

In 1975, Martinat collected A. demotella adults from June 23 to July 15. The oviposition site and behavior of early instars before overwintering are unknown at this time. The majority of A. juglandis adults emerge 2-3 weeks later than A. demotella moths (Martinat 1975). Eggs are laid singly on the undersides of leaflets (Gill 1917). After hatching, the larva moves a short distance and starts constructing a silk and frass case. The larva skeletonizes the lower layer of the leaf. The case is extended in a serpentine pattern as the larva grows (Figure 4). Necrosis

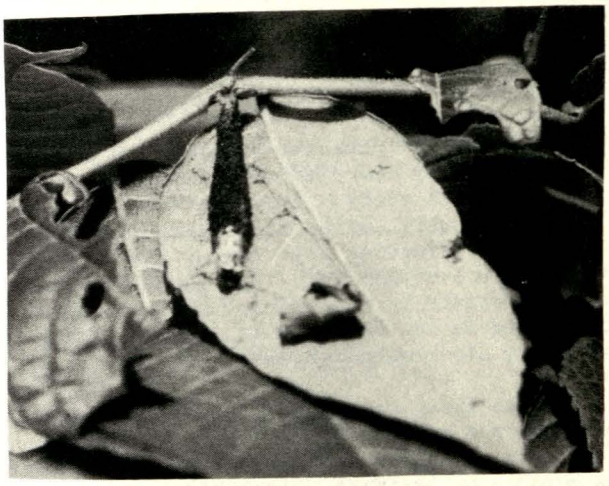

Figure 3.--Silk and frass case of late instar Acrobasis juglandis present in midsummer on the rachis of a walnut leaf.

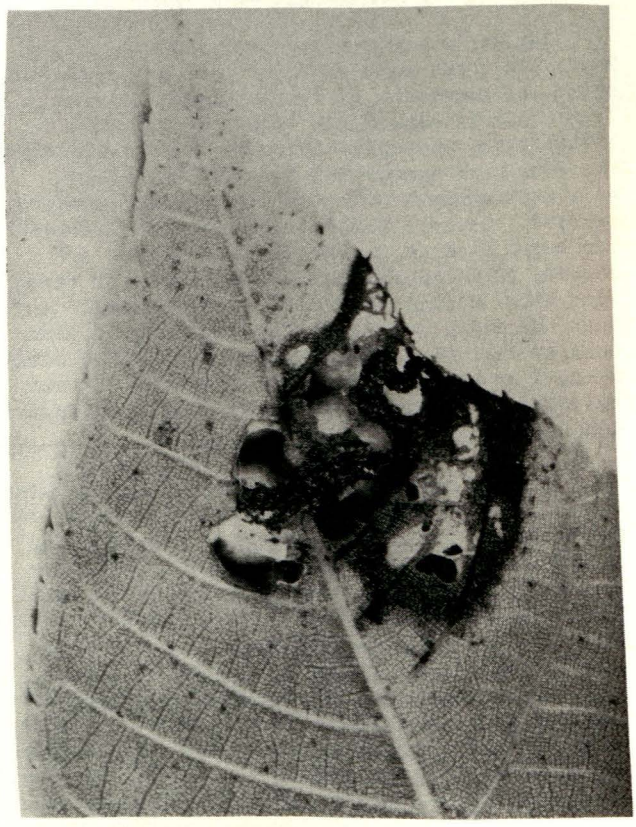

Figure 4.--Silk and frass case of early instar Acrobasis juglandis (or possibly A. demotella) on a walnut leaflet.

occurs where the leaflet has been skeletonized, giving them a blotched appearance. Just before leaf fall, larvae move to their overwintering sites near the buds.

MATERIALS AND METHODS (Insecticidal)

A 60 acre black walnut plantation located in Branch County near Quincy, Michigan, was chosen for this study. This plantation is particularly well suited to a study concerned with agents affecting tree form. Tree height ranges from 5 to 25 feet. During this phase, straight growth is crucial to the formation of clear wood in the first 16 ft. log of timber-producing black walnut trees.

Three spray tests were conducted using acephate and methoxychlor. Each treatment (acephate, methoxychlor, unsprayed) was applied to a block of 50 trees. Each block was separated by several rows of trees to minimize spray drift. Trees were sprayed with a 2 gal. hand sprayer using 2 to 3 tablespoons per gallon of each chemical. Trees 10 feet and under were chosen to facilitate spraying and data collection.

Two spray tests were conducted in early May. The trees were sprayed just prior to bud burst and emergence of early instar Acrobasis from their hibernaculae. In one plot, the entire tree, including branches and trunk, was wet down with spray mixture. In the other, only one terminal bud plus the branch were sprayed. Several weeks later, after larvae had begun feeding in the expanding buds and shoots, infested and uninfested buds per tree, plus those killed by frost, were counted. Any dead bud which had frass issuing from it, was counted as infested, although it may have been damaged by frost as well. A students' t test was used to compare post spray counts in sprayed and unsprayed areas.

Another part of the plantation was sprayed in September, a few weeks before leaf fall. At that time, Acrobasis larvae were free-feeding on the undersides of the leaflets. Spray was applied with a hand sprayer to the trees until the leaves were saturated. Just prior to spraying, counts of larvae and numbers of terminal buds per tree were taken. Post spray counts were conducted in May of the next year. Hibernaculae per terminal bud were counted. Percent mortality and confidence intervals were calculated, using Simmons and Chen's (1975) two-sample and four-sample methods for assessing insecticide efficacy.

RESULTS AND DISCUSSION

Efficacy data from the spring spray tests and the fall spray test suggest that both acephate and methoxychlor reduced the damage and numbers of Acrobasis. Of the two spray tests conducted in the spring, the treatment of single buds was about 10% more effective in reducing bud damage (Table 1). A single bud spray is more efficient because larvae move from hibernaculae to buds on the same branch. More thorough coverage of the bud may result from more careful spraying when only one branch tip is designated. Although the reduction of Acrobasis injury in sprayed blocks of the single bud test are greater, actual numbers of injured shoots are higher than in the whole tree spray test.

Acephate reduced Acrobasis injury on terminal buds by approximately 10% more than methoxychlor (Table 1). In this respect the fall spray data show results similar to the spring spray (Table 2). The mortality in the acephate sprayed plot was 20% more than that in the methoxychlor sprayed one. The differences between acephate vs. methoxychlor and the sprayed vs. unsprayed are statistically significant ($P < 0.05$). The "negative mortality" in the unsprayed block may be due to an error in the prespray count. Possibly all the eggs may not have hatched yet, or larval cases may not have been large enough to be seen during counting. Also, A. demotella larvae may not have been present on the undersides of the leaves, as the juglandis larvae are, at this time. This phase of its life history is not yet well-defined.

Another type of bud damage was observed during the follow-up to the spring spray tests. This was frost damage. Frost-killed buds were counted when infested buds were tallied. In each treatment, except the unsprayed block of the single bud spray, frost caused a greater percentage of the bud injury than did Acrobasis spp. larvae (Table 3). Nearly 100% of the buds on the trees in the whole tree spray area were injured by the combination of Acrobasis larvae and frost. Frost was much less damaging in the areas where the single bud spray test was conducted. Areas are not adjacent, which indicates that the differences in frost damage are due to variations in microclimate such as greater cold air collection in lower areas.

The incidence of frost damage is greater in sprayed plots than in unsprayed (Table 3). This could be synergistic effect of the spray, but, since the combined injury is not consistently greater in sprayed plots, probably not. Many buds may have been infested by Acrobasis larvae

first and later damaged by frost. Since it was not possible to determine definitely if frost or the insect had killed it, any bud which had frass and silk on or in it was counted as infested. Therefore, actual frost injury may be reasonably consistent, but seems to be lower in unsprayed plots where more buds were counted as infested.

The total percentage of injured buds remains at a relatively constant high level regardless of insecticide use. Because of this, a pruning technique was implemented to correct the forking of main branches after the terminal bud is killed, instead of trying to prevent it. Methods and results from a test of this cultural method follow.

MATERIALS AND METHODS (Cultural)

The pruning technique tested was not the usual procedure of removing the lower branches as the tree grows. This technique was designed to eliminate a fork in a branch the same year it forms. Only forks developing as a result of the terminal bud being killed (presumably by Acrobasis larvae or frost) were included.

Three treatments on approximately 50 trees each were employed. A terminal branch with 2 new shoots of approximately equal length and diameter near the tip were designated. On the 50 untreated trees these branches were simply numbered and labelled. For the first treatment, one of the 2 green shoots was removed and any other shoots further down the branch were left intact. For the second, all but one of the new shoots growing on the previous year's growth were removed so only one shoot forming the fork remained (Figure 5). These three treatments were executed randomly on 150 trees. The pruning was done in early June with a clean, sharp knife.

Table 1.--Efficacy data for spring spray of acephate and methoxychlor, Quincy, Michigan 1977

Treatment	Postspray[1]	Difference (Unsprayed-Sprayed)[2]
Single buds treated		
Acephate (n=54)	20% ± 0.7	34%
Methoxychlor (n=56)	30% ± 0.8	24%
Unsprayed (n=56)	54% ± 0.9	--
Whole tree treated		
Acephate (n=53)	10.0% ± 2.7	24.9%
Methoxychlor (n=48)	21.4% ± 3.1	13.5%
Unsprayed (n=52)	34.9% ± 4.7	--

[1] Mean ± standard error (percentage of terminal buds or shoots injured by Acrobasis).

[2] All differences between sprayed and unsprayed plots were significant (Students' t test, $P < 0.05$).

Table 2.--Efficacy data for fall spray of acephate and methoxychlor, Quincy, Michigan 1977

Treatment	Prespray[1]	Postspray[1]	Percent mortality[2]
Whole tree treated			
Acephate (n=50)	1.2 ± 0.2	0.3 ± 0.0	80.2% ± 9.2
Methoxychlor (n=49)	1.0 ± 0.1	0.4 ± 0.1	61.8% ± 18.1
Unsprayed (n=50)	0.7 ± 0.1	0.8 ± 0.1	-10.0% ± 32.8

[1] Mean ± standard error (number of Acrobasis larvae per terminal bud plus 15 cm of the branch).

[2] Mortality ± 95% confidence interval.

Table 3.--Comparison of Acrobasis injury to frost injury on black walnut (from postspray counts for spring spray test), Quincy, Michigan 1977

Treatment	Percent injured buds[1]		
	Acrobasis spp.	Frost	Combined
Single bud treated			
Acephate (n=54)	20% ± 0.7	52% ± 0.9	72% ± 0.8
Methoxychlor (n=56)	30% ± 0.8	55% ± 0.9	85% ± 0.6
Unsprayed (n=56)	54% ± 0.9	29% ± 0.8	83% ± 0.7
Whole tree treated			
Acephate (n=53)	10.0% ± 2.7	88.1% ± 3.2	100.0% ± 0.0
Methoxychlor (n=48)	21.4% ± 3.1	77.5% ± 4.9	95.1% ± 2.5
Unsprayed (n=52)	34.9% ± 4.7	63.6% ± 4.8	99.7% ± 0.2

[1] Mean ± standard error

In May of the following year, the pruning treatments were evaluated. A determination of whether the fork had been eliminated ("corrected") or not was made and measurements of the new (1977) and last year's (1976) growth on both treated and untreated branches were recorded. Healing of the branch where shoots had been removed, based on closure of the wound, was noted.

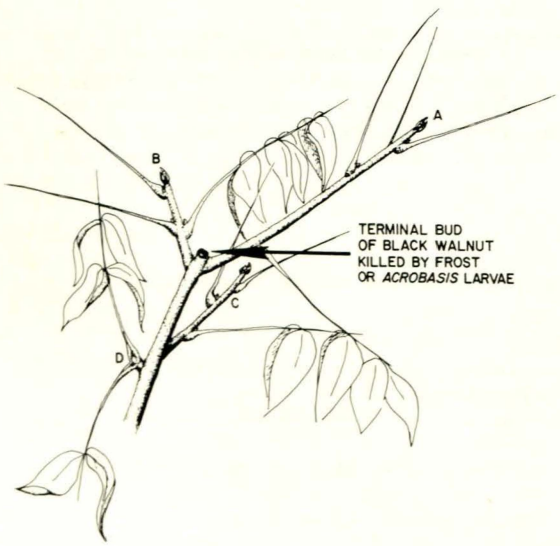

Figure 5.--Pruning techniques for correcting forking: 1) only B is removed, 2) B, C, and D are pruned and A becomes the terminal leader. Shoots were pruned in early June with a sharp knife.

RESULTS AND DISCUSSION

This pruning technique appears to have corrected forking effectively. Forks were counted as "corrected" when only one shoot remained as the main leader and if the branch appeared to be nearly straight. On many of the branches where only one shoot was removed, another one further down the branch grew enough to form a fork comprised of it and the shoot left from the original 2 (Table 4). Removing all but one of the new shoots was effective in all instances.

The pruning of a single shoot resulted in a slight increase in growth compared to the untreated branches, but not enough to be statistically significant (Table 4). The treatment in which all but one shoot was removed did result in significantly greater growth. The ratios of 1977 growth to 1976 growth were used to compare the effects of each treatment on shoot growth. This was done to eliminate the bias towards faster growing trees in the second treatment.

Table 4.--Results of "corrective pruning" to reduce Acrobasis and frost injury on black walnut, Quincy, Michigan 1977

Treatment	Forking corrected?		Mean length in feet of branch growth[1]		Ratio[2]
	Yes	No	1977	1976	1977/1976
Single shoot removed (n=39)	62%	38%	0.7 ± .06	1.2 ± .09	0.6 ± .06
All shoots but one removed (n=34)	100%	0%	0.7 ± .06	1.2 ± .10	0.7 ± .09[2]
Untreated (no shoots removed) (n=45)	7%	93%	0.6 ± .04	1.2 ± .07	0.5 ± .04

[1] Mean ± standard error
[2] Significantly greater than untreated (Students' t test, $P < 0.05$)

Healing of the pruning wounds occurred very quickly. On the majority of branches, branch stubs were nearly healed over by the end of the growing season. Branches where all but one shoot was removed, healed faster than those where only one was removed. This may have been due to the increased growth of those branches.

SUMMARY

The results of this study suggest that acephate and methoxychlor are effective in reducing Acrobasis spp. damage and numbers. Either one may be sprayed in the early spring or early fall. Both chemicals are also effective when sprayed on single buds (spring test). This approach is more effective than whole tree spraying and can reduce spray and time consumption. Acephate was 10 to 20% more effective than methoxychlor in all three trials.

However, insecticides do not minimize frost damage which causes a major portion of the bud injury in some years. The pruning technique tested can correct forking caused by both frost and Acrobasis feeding, as well as increasing growth of the terminal shoots.

RECOMMENDATIONS

Our recommendation to walnut growers in Michigan is to correct forking of terminal branches by pruning rather than by applying insecticides. The new shoots developing along a branch may be removed, leaving one to become the terminal leader. This should be done in early June when bud damage is apparent and before shoot growth is completed. This treatment is only necessary on terminal branches in years when frost and insect damage is severe.

ACKNOWLEDGMENTS

Our sincere thanks to S. Wilson, J. Pasek, J. Nyrop, N. Krite, B. Kemp, and J. Ball for field assistance and to Mr. George Brown, owner of the black walnut plantation near Quincy, Michigan, for his cooperation. This work was supported in part by a grant from the U.S.D.A. Forest Service.

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GROUP DISCUSSION

Kuntz: Do you find any continued discoloration down the stem from the Acrobasis injury? Is there any associated dieback?

McKeague: We haven't found any.

Kuntz: Have you found any evidence of Melanconium fungus coming in on any of these injured twigs? Have you seen any sooty pustules or fruiting bodies?

McKeague: No, I haven't seen any evidence of disease.

L. Wilson: I haven't noticed anything with the butternut curculio either.

Schlesinger: Do you think that repeated single leader pruning on a tree which is continually attacked by Acrobasis will cause problems?

McKeague: If continual attack is a problem, I can't see that the repeated pruning would be a problem. We're not determining if there is only a single branch coming up. We're looking at the terminal leader. The lateral branches, of course, are not as crucial.

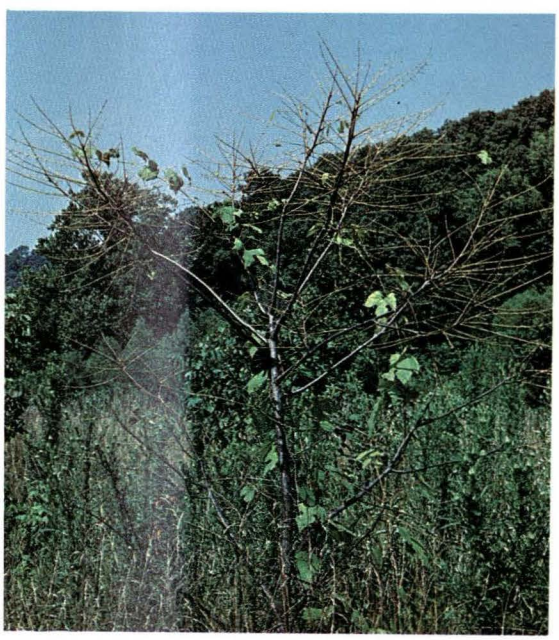
Schlesinger: No, I was just wondering if you would end up with a single leader if you pruned year after year. You are not allowing the laterals to develop on that growth.

L. Wilson: This is probably an area where we might continue some research because it brings up a good point. What does happen to the trees? Perhaps this is something we can bring up tomorrow as a potential future study.

Shigo: In your abstract you state that "all but one of the new shoots of a damaged branch were removed in late summer," while in your presentation you said June. Can you clarify that?

McKeague: Yes. That was evidently a typing error. It should have said "early summer", since the branches were pruned in early June.

Feeding walnut caterpillars.



Walnut caterpillar defoliation.

Walnut caterpillar 5th instar.

Fall webworm.

Dieback of young leaves due to *Acrobasis* attack.

Frass typical of entrance by *Acrobasis* larva into newly expanding terminal bud. (Photo courtesy of W. H. Hoffard, S&PF, Asheville, NC.)

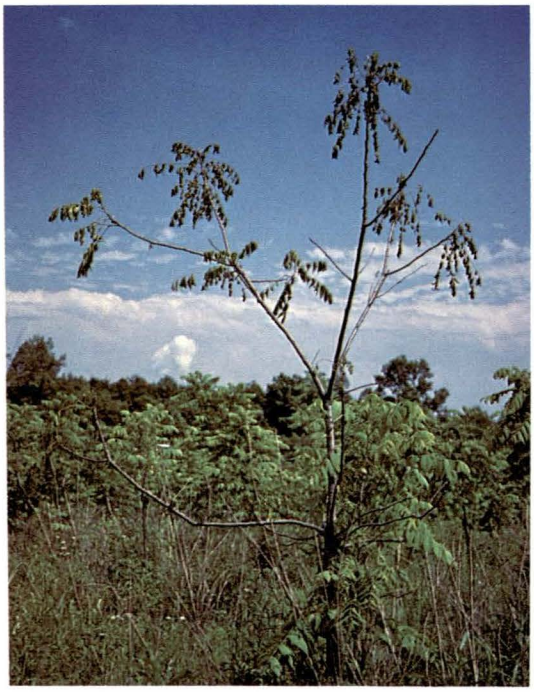
Tunneling larva of *Acrobasis demotella*.

Oviposition injury to walnut fruit caused by walnut curculio.

Phytophthora root rot.
(Photo courtesy of R. Green,
Purdue University.)

Cylindrocladium root rot.
(Photo courtesy of
D. A. Roth and G. J. Griffin,
VPI)

Anthracnose lesions on walnut
foliage and fruit.



Wilting foliage caused by stem girdling from a Fusarium canker.

Bark removed to show discoloration associated with Fusarium canker.

Butternut decline.

THE BLACK WALNUT CURCULIO AND ITS IMPACT ON NUT PRODUCTION

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Kansas State and Extension Forestry
Kansas State University
Hutchinson, Kansas

and

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University of Missouri
Columbia, Missouri

ABSTRACT:--The black walnut curculio, Conotrachelus retentus (Say), is an important pest to black walnut nut production. Adult curculios feed on walnut foliage and oviposit on developing nuts in May and June. The infested nuts drop from trees before reaching maturity. Missouri nut productivity studies conducted in 1976-77 revealed curculio related losses of 78%, 66%, 43%, and 19% to nut crops in three geographic areas of the state. The black walnut curculio was found to be the major factor among four factors which influenced early nut drop in black walnut.

Expanded uses for black walnut nuts have added a new and potentially profitable aspect to walnut farming. Demand for nut products is steadily increasing, and management practices now recognize and support nut production as an economic plus for the species. Annual incomes from nut crops reduce the long-term carrying costs associated with plantation establishment and cultural operations. These costs are normally cancelled only when the trees are harvested at the end of the rotation.

Black walnut nuts are valuable both from the standpoint of regeneration and industry. Increased landowner awareness of the value of walnut timber has caused a significant increase in demand for walnut seedlings. Most states have been unable to meet these demands because of nut scarcity (Grey 1973). This problem has been complicated by competition from the nut industry. Aside from the importance of the walnut kernel as a food item, research has shown important uses for crushed shells. Among these are use as filter agents in smokestack scrubbers, additives to drilling mud in oil well drilling, polishing agents for chrome and automotive parts, and many others (Cavender 1973). Poor quality walnut kernels which were once wasted are now ground and added to livestock feed as a nutritional booster. Continued research promises additional uses for black walnut nuts in the future.

Insects which affect nut productivity must be considered an important component of black walnut management. The black walnut curculio, Conotrachelus retentus (Say), is an important pest. The adult feeds on new shoots and leaves, and the larva destroys the developing nut. Little information has been available on the habits of this pest. Therefore, a comprehensive study was conducted in 1976-77 to determine its life history and impact on nut production in Missouri.

LIFE HISTORY

The life cycle of the black walnut curculio encompasses about 13 months. Adult curculios overwinter in the soil or under organic litter on top of the soil. Spring emergence begins in mid-April and continues for several weeks. Newly emerged adults enter the nearest black walnut tree and feed on succulent foliage and staminate flowers. Feeding damage occurs primarily on the base of the leaf rachis, and appears as a small darkened area. This damage seldom causes leaf death, and is difficult to detect. Occasionally, the curculio chews holes in walnut leaflets, but this damage cannot be distinguished from that of other leaf-feeding beetles.

Oviposition begins on developing nuts shortly after the female flowers are fertilized. In young nuts, single eggs are placed in crescent shaped punctures chewed from the wall of the nut. More than one crescent may be present on a nut, and several eggs may hatch. However, the most vigorous larva will consume the others to insure an adequate food supply for its own development. On larger more mature nuts, single eggs are placed in ovipositional punctures which resemble pin holes. These punctures are usually placed on the nut in clusters of 3-10. It is not uncommon for several larvae to complete their development in large nuts with diameters of 3.8 cm or larger.

Rarely, black walnut curculios oviposit in elongating shoots of black walnut. The developing larva generally tunnels toward the terminal bud to remain in succulent tissue. Surveys of Missouri black walnut plantations under 10 years of age revealed no curculio activity in young trees. Adult curculios evidently do not associate with trees too young to bear nut crops. All oviposition is complete by the end of June.

The curculio larva hatches from the egg about 5 days after oviposition. The larva bores into the center of the nut and consumes its contents. The infested nut drops from the tree about 3 weeks after oviposition occurs. The larva remains inside the hollowed out nut for an additional 2 weeks before entering the soil to pupate. When fully grown, the larva is about 11 mm long. Duration of the larval stage is about 5 weeks.

The larva exits the nut by chewing through the nut wall. Exit holes are about 5 mm in diameter, and serve as evidence of curculio activity. After entering the soil, the larva forms a smooth-walled cell where it undergoes physiological changes for several days prior to pupation. The pupal stage occupies a period of about 3 weeks.

Summer adult emergence begins in mid-July and continues into August. These adults feed on black walnut foliage until leaf drop occurs. No reproduction takes place until the following spring.

IMPACT ON NUT CROPS

Missouri nut productivity studies were conducted in one area in 1976, and three areas in 1977. The initial study involved testing and comparison of three trapping variations at the Dupont black walnut plantation near Ashburn, Missouri. Trees in the plantation were 27 years old at the time of the study. Thirty-six trees were selected and sampled with 216 cone-shaped plastic traps (0.8 m diam). Each trap was suspended between two 5 foot stakes (132.4 cm). Trap placement was statistically designed to accurately estimate damage for the entire plantation from sample tree collections.

Traps were checked weekly from early June until August, and biweekly for the remainder of the season. The collected nuts were dissected to determine the reason for early drop. Records were kept for each nut. Four factors were determined to influence premature abortion and loss to nut crops. These included curculio damage, infertility, squirrel activity, and natural abortion in response to moisture stress. Curculio damage had the greatest impact of the four factors. It accounted for 88% of the premature drop recorded during the 2 years of productivity studies.

Seasonal nut drop at the Dupont plantation in 1976 occurred in two distinct periods (Figure 1). The "June nut drop" included all nuts which dropped before August 17 as a result of the four previously mentioned factors. These nuts were lost to production. The mature nut drop occurred from September 15 to November 5. Nuts which dropped during this period were harvestable. The black walnut curculio reduced the nut crop by 43% at Dupont in 1976.

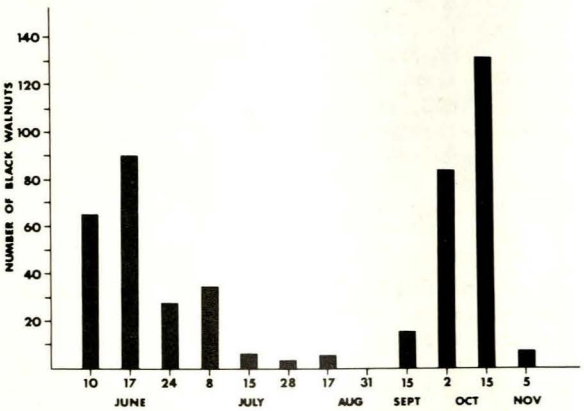

Figure 1.--Seasonal distribution of black walnut nut drop at the Dupont plantation, Ashburn, Missouri, in 1976.

The 1977 black walnut productivity study was expanded to include trapping sites in three geographic areas of the state. The Dupont plantation was again used to represent the northeastern part of Missouri. An unmanaged tract of black walnut near Fayette, Missouri was used as a central Missouri site. The third site was an intensively managed black walnut fertilization plot in southwestern Missouri, near Stockton. Sample trees were of nut-bearing age, and ranged from 24 to 32 cm DBH. Thirty trees were randomly selected in each area. Each tree received four traps.

Seasonal nut drop at the Dupont plantation differed greatly in 1977 from that of the previous season (Figure 2). Only a small percentage of the nuts reached maturity. Disregarding other factors, curculio damage was responsible for a 78% reduction of the potential harvestable yield.

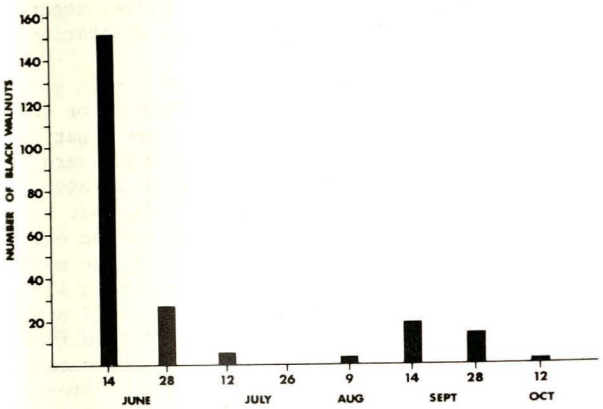

Figure 2.--Seasonal distribution of black walnut drop at the Dupont plantation, Ashburn, Missouri, in 1977.

A similar level of damage was recorded at the Fayette trapping site (Figure 3). Again, more nuts were collected during the June nut drop than during the mature drop. Sixty-six percent of the crop was destroyed by curculio activity.

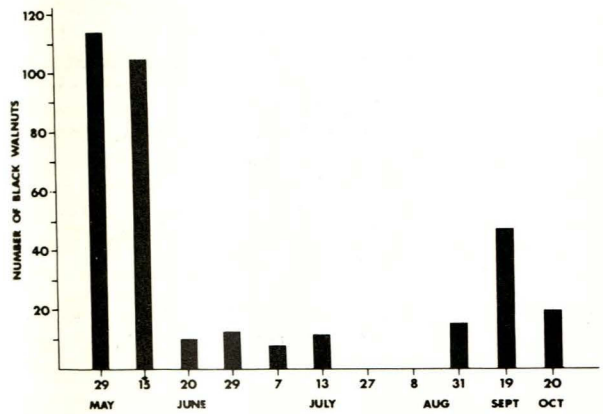

Figure 3.--Seasonal distribution of black walnut nut drop in natural forest, near Fayette, Missouri, in 1977.

The Stockton area was least affected by premature nut drop (Figure 4). Most of the crop reached maturity at this site. Curculio activity destroyed only 19% of the developing nuts. This level of damage was not consistent with other Missouri areas. The comparatively low impact was possibly linked with site disturbance effected by former practices in the stand. Activities which affected the site included annual applications of simazine and paraquat to remove grass under trees, bulldozer work to release single trees, and the use of heavy equipment in an intensive spray schedule involving foliar fertilizer. It is believed that the combination of compacted soil and lack of normal ground cover may have adversely influenced curculio populations on the site. This might explain the reduced level of curculio damage.

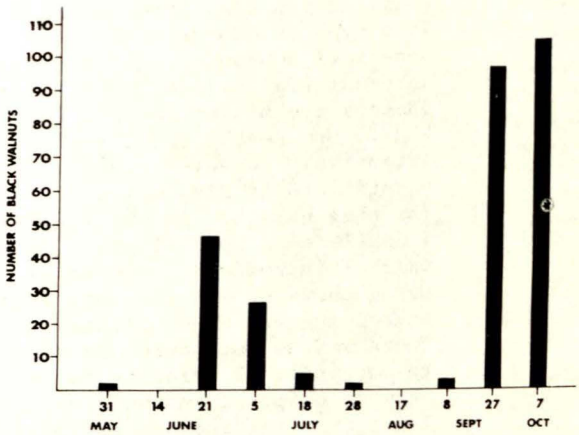

Figure 4.--Seasonal distribution of black walnut nut drop at the Fox plantation, Stockton, Missouri, in 1977.

CONCLUSIONS

Seasonal nut collections in 1976 and 1977 showed that the black walnut curculio had an important impact on black walnut nut production in Missouri. Statewide, 51% of the nuts collected in productivity studies dropped prematurely as a result of curculio activity. This indicates that control measures may be warranted where annual incomes from nut crops are desired. Continued research is needed in developing a sound control program to reduce the impact of this pest.

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GROUP DISCUSSION

Weber: One comment about what we are finding in southern Illinois. We do find Conotrachelus retentus weevil adult ovipositing in the newly developing leaflets in the spring. We find that eggs inside the petiole and some years there is a lot of that kind of damage in southern Illinois.

Blair: Well, that's real interesting. This type of damage could have some real economic ramifications in young plantations where these insects are mining out the terminal buds. Dr. Kearby and I rather extensively surveyed several plantations in Missouri and looked for this damage. In the laboratory I initiated a special study in which I introduced a number of mated pairs of weevils into cages containing walnut seedlings. There was no nut source in which to oviposit. I tried to force them to oviposit in the stems and I got only one instance of petiole oviposition in two years. I artificially inoculated some of the stems with eggs that I had collected and they hatched and developed normally. So we feel that it really is not a problem in Missouri. So I am glad to hear that it is a problem down here in this part of the country.

LaMadeleine: You said that you had some help in developing your statistical survey technique and that you had a phenomenal number of sampling bags there in the study area. Do you have a feeling for how many samples are necessary to determine impact on an area? How would you set up your system?

Blair: In the first study, we studied 6 trees and used either 4, 6, or 8 traps. We found that there was no statistical variation between the means collected in either 4, 6, or 8 traps. So, in our expanded program we used 4 traps per tree and found that we needed a minimum of 30 trees in an area to really mean anything to us. So we went with 30 trees to study weevil impact on the trees.

LaMadeleine: Then you used 30 trees, regardless of the size of the plantation?

Blair: Right. Our method was to go in and map the plantation, or mark the trees. If it was a native stand, our sample trees were then selected by means of a random numbers table. To further randomize the design, we marked off 8 sections beginning at due north and rotating through each 45 degrees in a clockwise direction around each tree and drew from a random numbers table to determine where the trap would go around that tree. It was a very complete job of statistics.

Weber: Have you reared out any other species of Conotrachelus?

Blair: I did. This was almost a fluke. I reared one Conotrachelus elegans which is the big nut curculio. I sent it to Lester Gibson in Ohio for positive identification and he wrote me a letter confirming the identification but also indicating surprise. The specimens were in containers where we were using sterilized soil and rearing anything that came out. I have found Conotrachelus elegans associated with black walnut nuts for quite some time and always thought that they might complete their development in the nut itself. They feed readily on the foliage and act very similar to Conotrachelus retentus in their life cycle.

Weber: The reason that I asked was that I have reared out Conotrachelus anaglypticus which is a pest on fruit trees.

THE LIFE HISTORY OF ACROBASIS DEMOTELLA AND ITS ROLE IN SEEDLING AND SAPLING STEM DEFORMITIES IN MISSOURI[1]

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ABSTRACT.--The lepidopterous shoot borer, Acrobasis demotella Grote, is the most destructive borer in terminal shoots of black walnut seedlings and saplings in Missouri. The larvae overwinter in hibernacula and emerge at bud swell to feed on buds and tunnel in shoots. Larval activity occurs during April and May. The larvae exit the shoots and move to the soil to pupate. Adults emerge in June and lay eggs on the foliage. After eclosion the larvae feed on leaves prior to forming hibernacula near the axils or bases of new buds. It is univoltine.

The impact of this insect is stem deformities on 1 to 5 percent of the trees grown in plantations in North Missouri in most years.

In Missouri the black walnut tree affords the greatest opportunity for long-term economic gains when compared to other forest or plantation grown trees by providing nuts, shells, lumber, and veneer logs. Add to these the multicrop concept such as a cow-calf operation with grass, wheat or soybeans and a sustained economic operation is underway. However, with relation to geographic location and site factors, particularly soil, drainage, slope and elevation, several problems may occur annually when attempting to establish a new plantation. Annually black walnut seedlings and saplings have been damaged by flooding, frost, mammals, pathogens and insects. Kearby (1976) reported 62 species of insects feeding on various parts of black walnut trees during 1974 in Missouri. Of these the bud and shoot feeding insects were the most important, since loss of terminal buds and shoots on young trees adversely affects their future form. This paper discusses only one species, a pyralid, Acrobasis demotella Grote.

SITE SELECTION

Two major vegetative geographic areas were examined in Missouri. The prairie, where black walnut grows along creeks and larger streams in Boone, Carroll, Clay and Macon Counties north of the Missouri River, and the oak-hickory forests of Cedar, Dade, Hickory and Texas Counties south of the river. The topography varies from level to rolling or hilly slopes.

SAMPLE UNITS

In plantations and natural stands, seedlings and saplings to a height of 3 meters were examined for various stages of Acrobasis demotella and damage. The sample units were terminal buds, terminal shoots, lateral buds, and lateral shoots. The terminal buds are those buds on the apical 3 cm of the terminal shoot. The terminal shoot is that shoot which assumes apical dominance during the form-phase of seasonal growth. The lateral buds are those buds on branch whorls 1 and 2 below the terminal shoot. The lateral shoots are new shoots that arise from whorls 1 and 2.

METHODS

The sample units were examined biweekly and weekly during the growing season and twice during the winter. The number of seedlings and saplings examined at each site varied with the size of the plantation or natural stand from 25 to 200 individuals. Those that showed previous shoot deformities were tagged and numbered for study. Trees that had no previous deformities were added to the study when overwintering hibernacula and early season shoot boring was observed at the eight sites. Termina and lateral shoots were removed throughout the year and were examined in the laboratory for hibernacula and other immature stages of A. demotella. Infested shoots were used in rearing experiments in temperature controlled environmental chambers to observe development of the life stages.

[1] Not presented at workshop.

BIOLOGY

Acrobasis demotella 1st and 2nd instar larvae overwinter in hibernacula located on the terminal buds or in the axils of lateral buds (Figure 1). The hibernacula range in length 1.1-1.5 mm and 0.8-0.9 mm in width. They are downy and gray and blend well with buds of black walnut. The larvae emerge from the hibernacula at bud swell and feed on the expanding buds. As shoot elongation occurs, a larva will bore into the axil where the leaf petiole attaches to the shoot. The larva tunnels downward into the pith 2 to 5 cm. The presence of a larva in an elongating shoot is noted by a small amount of loose frass and silk near the entrance hole. Larval feeding in shoots occurs in April and May. Most larvae complete feeding by late April. The last stage larva is 14 to 17 mm long, head reddish brown or dark brown and the body is purplish with green undertones (Neunzig 1972). The larva leaves through the enlarged entry hole in the shoot and moves to the soil. Pupation occurs just beneath the soil surface in a thin cocoon surrounded with soil particles. In the field moths emerged the last week of May through mid-June. In the laboratory fertile females laid single eggs on leaflets of caged seedlings. A few larvae hatched and fed lightly on the undersurface of the leaves. Within a week the 1st or 2nd stage larvae moved to the stem and spun hibernacula. In the field hibernacula were observed on buds in August. It has a single generation each year.

DAMAGE

Black walnut saplings on poor sites are adversely affected by A. demotella larvae feeding on small terminal bud clusters. The larvae may destroy the entire cluster or only the terminal bud prior to expansion of the shoot. This feeding causes a blunt shoot or a forked top. The injury is similar to a very early frost but is not uniform throughout the stand.

Last stage larvae usually leave the shoots prior to any noticeable shoot symptoms. Wilted shoots with necrotic leaflets occur above the larval tunnel in late May and early June (Figure 2). Damage by A. demotella can be separated from April frost damage by the tunnelled pith contrasted to shriveled hardened pith. Insect damage is scattered throughout a stand whereas frost damage is uniform on adjoining trees or the entire stand. Tunnelled shoots dry and break and leave a blunt stub or a portion of the hollowed shoot intact (Figure 3).

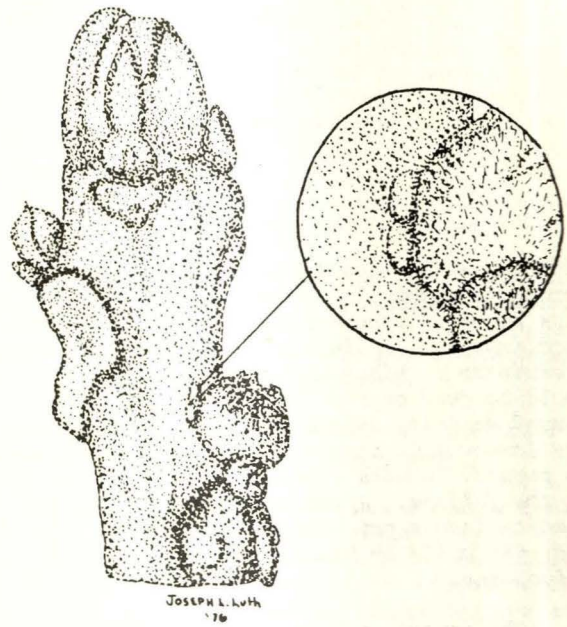

Figure 1.--Diagrammatic illustration of a black walnut terminal showing the location of the hibernacula.

CONCLUSION

In north Missouri on the best black walnut sites A. demotella is one of the major causes of stem deformities. However, other insects particularly scarab beetles, cause early bud loss (Kearby 1976). The total shoot loss in a plantation may range from 1 to 5 percent a year. This varies with sapling size and the same trees are not re-infested in successive years. Therefore, shoot damage becomes compounded over a 5-year period. Trees that expand rapidly in the spring are less susceptible to bud and shoot injuries caused by A. demotella and other insects. Only the better sites should be selected for planting to prevent excessive insect deformities.

Figure 2.--Terminal shoot mortality caused by the larva of A. demotella.

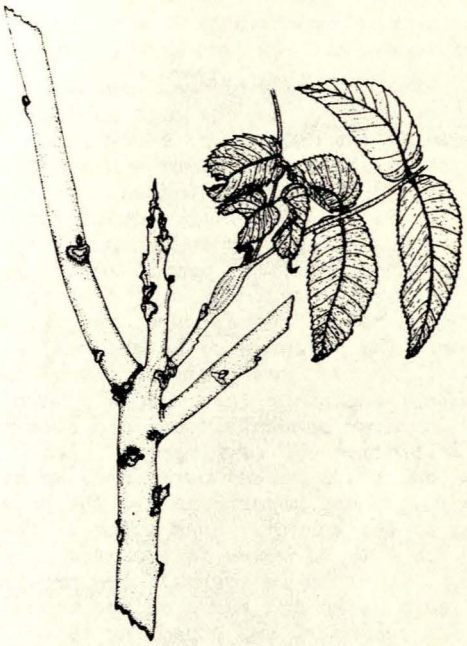

Figure 3.--Diagrammatic illustration of a tunnelled black walnut terminal after the tip has broken off in midsummer.

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ETIOLOGY, EPIDEMIOLOGY AND CONTROL OF BLACK WALNUT ANTHRACNOSE

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ABSTRACT.--Walnut anthracnose, caused by Gnomonia leptostyla, is the most serious and widespread foliar disease of black walnut. Literature on the causal agent and etiology and control of the disease is limited. In Illinois studies, we have isolated the causal fungus from trees from several states and compared the cultural characteristics, growth rates, sporulation, and spore germination of the isolates with several media, temperature, pH, and light variables. The presence of heterothallism was confirmed. We have artificially inoculated black walnut seedlings (and mature plants) with varying inoculum concentrations and observed lesion initiation and development. Leaf rachises are the apparent overwintering site for the fungus and ascospores are the primary inoculum in the spring. Free water on the leaf surface for 6 to 24 hours is essential for infection. Conidia in acervuli are produced after 2 to 3 weeks and serve as the inoculum source for secondary and repeating infections. Lower light intensities favored disease severity. Species and hybrids of Juglans varied in resistance to Gnomonia leptostyla. Partial control of disease in the field can be obtained through fertilization with nitrogen fertilizers and application of protective fungicides (especially benomyl) during the last week of May and the first week of July.

Walnut anthracnose, caused by Gnomonia leptostyla (imperfect stage--Marssonina juglandis), is the most serious and widespread foliar disease of black walnut. Literature on the causal agent and etiology and control of the disease is limited. Only three individuals have conducted extensive research on Marssonina juglandis: H. Klebahn in Germany in the early 1900's, F. H. Berry in Maryland in the 1950's, and J. Fayret in France in the 1960's and 70's.

Klebahn recognized the disease on black walnut. He described the symptoms and the asexual fruiting bodies of the fungus on the leaf surface. He also isolated the causal fungus to pure culture and established its pathogenicity with infection experiments. In addition, he described the fungus in agar culture and observed both macroconidia and microconidia. Klebahn obtained perithecia from overwintered leaves and studied and described the perfect stage of the fungus.

Berry was interested in the etiology and control of the disease. He collected perithecia from overwintered leaves and observed the discharge of ascospores, the primary inoculum, in the spring. He also observed the occurrence on leaflets of acervuli and conidia, the inoculum for secondary infection, and associated their dissemination with rainfall. He found few overwintering sites other than the perithecia on fallen leaves. Berry was able to artificially inoculate plants successfully and related infection with rainfall. He observed anthracnose infections on 40 varieties of black walnut and applied foliar sprays and ground sprays of fungicides in control studies.

Fayret reported on the mycology of Gnomonia leptostyla. He found that perithecial production was favored at temperatures between 7° and 10° C and was slightly reduced by light. He reported that as photo-inhibition of sexual morphogenesis progresses, photo-induced conidiogenesis increases. Acervulus production was greatest at 18° C, and microconidia were produced at 10° C. He established that the union of two complementary mating types (heterothallism) is required for perithecial production.

In our studies in Illinois, we have obtained additional information on (1) the severity of the disease on black walnut and its effects on the host plant, (2) the factors influencing growth and sporulation of the causal fungus and germination of the spores, (3) the microenvironmental variables regulating the inoculum at the infection site, (4) the climatic factors governing epidemiology in the field, (5) the resistance to disease within the genus Juglans, and (6) the cultural practices that control or reduce the effects of the disease.

[1] I wish to acknowledge the contributions of William M. Black and James A. Matteoni, who while graduate research assistants at the University of Illinois, contributed substantially to our better understanding of this disease.

SEVERITY

In a five-state, 1200-mile survey in 1975, we examined roadside black walnut trees and collected diseased leaf specimens for examination and isolation. G. leptostyla was the predominant cause of leaf lesions. Microstroma juglandis and Cristulariella pyramidalis were two additional fungus pathogens found on walnut, but the major causes of premature leaf yellowing and defoliation, other than anthracnose, are noninfectious agents.

MYCOLOGY

The growth of G. leptostyla on all laboratory culture media was slow with more than three weeks' incubation required for the fungus to form a 9.0-cm wide colony. Oatmeal agar was the most favorable medium for vegetative growth and asexual sporulation of the fungus.

The fungus grows on culture media with an initial pH ranging from 4.5 to 10, but grows best on media with pH 5.0 to 7.0. Vegetative growth and sexual sporulation are favored at the lower pH, with asexual sporulation favored at the higher pH. Leaf pH may be one of the factors determining the change from the production of the conidial stage on attached leaves to the microconidial and perithecial stages on the more acidic fallen leaves.

The fungus is adapted to moderate temperature. An incubation temperature of 22° C was optimum for vegetative growth, and 26° C was optimum for asexual sporulation. The sexual stage is formed in response to cooler temperatures, 6° to 10° C. No growth was observed in vitro at 30° C.

Light favored asexual sporulation but reduced vegetative growth. The development of the sexual stage was favored by darkness, which would prevail in the decaying host material in leaf litter.

Provenance studies of fungus isolates indicated only random, limited variation in growth, germination, and sporulation of fungal cultures from several states.

Germination of spores taken from isolates maintained in pure cultures or obtained directly from infected leaves occurred rapidly. While no significant germination of ascospores took place within 6 hours, within 12 hours 40% germination occurred at temperatures ranging from 18° to 30° C, with optimum germination at 26° C. Nine hours were required for significant conidial germination. Optimum temperatures were 22° to 26° C. Neither germination in culture nor infection of leaves was observed with microconidia exposed to favorable temperature, moisture, and nutrient conditions.

The presence of heterothallism was confirmed. All self-crosses were sterile. Colony types producing either protoperithecia or black perithecium-like structures, as described by Fayret, were observed, and crosses between isolates with different colony types produced perithecia with mature ascospores.

PATHOGENESIS

Two artificial inoculation procedures were employed. To provide moist environments, either a leaflet was enclosed in a plastic petri dish (Latham method), or several leaves were enclosed in a plastic bag that was gathered and tied around the plant stem. After a brief post-inoculation period, the humidity chamber was removed. Disease symptoms were abundant within 14 to 21 days under optimum conditions.

The study on inoculum concentration revealed that 100,000 conidia/ml gave the greatest number of lesions per leaflet, but that lesions developed from inoculum concentrations as low as 10 conidia/ml. With decreasing duration of free moisture on the leaf during the post-inoculation period, there was decreasing effectiveness of the inoculum. Under optimum laboratory conditions there was a logarithmic increase of infection frequency from 6 to 12 hours into the post-inoculation period.

In other infection experiments, the source of inoculum seemed to be of no special consequence: inoculum obtained from laboratory cultures or taken from lesions on affected trees seemed equally pathogenic. Substantial variability occurred in host plant susceptibility, however.

No differences in lesion character resulted from upper and lower leaf surface inoculations, but there was a great difference in infection frequencies. Nearly 10 times as many lesions resulted from placing the conidia on the lower surface.

The age of the leaf was related to disease susceptibility. Walnut is indeterminate in growth habits, and the immature, expanding leaves were not as likely to become infected as were the fully expanded leaves. In greenhouse tests using five distal leaves, all exhibited some lesions, but the lesions were

smaller than normal on the three younger leaves and acervuli did not form on the two youngest ones. Lesions were large and acervuli abundant on the two older leaves.

Observations of fungal penetration were inconclusive. Scanning electron microscope studies indicated direct penetration through the cuticle and epidermis, with appressoria and penetration pegs. Penetration may also occur through glandular hairs. Stomatal penetration was not observed although it remains a possibility.

EPIDEMIOLOGY

Experiments related to the severity of walnut anthracnose were performed on seedlings in the greenhouse, in controlled-environment chambers, and on young trees in the field. When artificial inoculations were required, spore suspensions (5×10^4 conidia/ml) were brushed onto the upper and lower surfaces of the leaves (1 ml/leaf), which were then enclosed in a plastic bag, usually for 48 hours.

Attempts to isolate the pathogen from overwintering tissue proved difficult, since abscised leaflets decay rapidly. In one collection from Carbondale, however, 50% of the leaflets contained G. leptostyla perithecia. Pure cultures were obtained from these perithecia. Rachises of the compound leaf are very likely to overwinter intact. Seven percent of the rachises from Urbana collections contained perithecia, as did 25% of those from Carbondale. Perithecial production on dormant woody twigs was very limited, only three perithecia on bud scars on 200 twigs.

Spore trapping in Urbana confirmed previous observations that ascospores constitute the primary and conidia the secondary inoculum sources. Ascospores were trapped primarily between May 15 and June 5. Conidia were trapped after June 1, with the greatest number recorded between July 1 and July 31. A high correlation existed between total spores trapped and days with measurable rainfall.

Laboratory simulation verified the importance of precipitation for conidial dispersal. Wind alone or wind-blown wet leaves did not liberate spores from acervuli on infected leaves. Simulated rainfall onto wind-blown leaves, however, resulted in great numbers of liberated conidia.

Conidia on leaves abscised for 2 weeks or 1 month were just as virulent as mature conidia from lesions on leaflets still in the tree crown.

The effect of temperature on infection and disease development was investigated in controlled-environment chambers. Incubation of artificially inoculated plants at 21° C resulted in the maximum infection, while at 15° C significantly fewer lesions were evident. At temperatures of 10° C and below and 27° C and above, few lesions resulted. When plants incubated at 10° and 15° C were transferred to 21° C chambers, latent infections became evident. This phenomenon was not observed on plants originally incubated at 27° or 32° C.

Free moisture on the leaf surface is essential for infection. At 32° C during the post-inoculation period, only 1% to 3% infection occurred no matter how long free moisture remained on the leaf surface. At 21° C, as time with free moisture increased from 6 to 24 hours, the proportion of leaflets that became symptomatic increased from 3% to 90%. At 10° C post-inoculation temperature, significant increases were noted as time increased up to 48 hours.

Free moisture need not be present at the time the inoculum comes to rest on the leaflet surface. The inoculum retained infectivity on dry leaves for up to 2 weeks, and upon wetting of the leaf, lesions resulted. The longer the dry period, the fewer the lesions.

The anthracnose pathogen was capable of infecting susceptible tissue only within a narrow range of relative humidity (98% to 100%). High relative humidity promotes infection primarily through the prolongation of the time that free moisture remains on the leaflet surface.

Light intensity also had a significant effect on walnut anthracnose severity. Shaded seedling plants had from 80% to 90% of the foliage infected. Plants under clear glass had 13% of the foliage affected, and plants in full sunlight had 8% of the foliage affected.

A period of darkness during the first hours of the post-inoculation period resulted in an increase in the percentage of inoculated leaflets infected. Forty-eight hours of continuous darkness or of dark/light in a 12-hour cycle gave significantly more infections than did continuous light or light/dark in a 12-hour cycle.

Seedlings growing slowly in a heavy soil potting mixture in the greenhouse were more susceptible to anthracnose than were their vigorous counterparts growing in a fertilized peat:sand potting mixture.

The availability of soil moisture at the time of inoculation (within 48 hours), varying from 50% to 100%, did not appear to affect susceptibility to the anthracnose pathogen. When these moisture levels were maintained throughout the incubation period (2 weeks), the drier plants exhibited fewer lesions.

RESISTANCE

Artificial inoculation of various nut trees revealed a wide variation in host resistance to Gnomonia leptostyla infections. Leaf lesions developed on walnut, butternut, and heartnut, but no infection was evident on chestnut, hickory, or pecan. Arizona walnut and black walnut were very susceptible, whereas the clones of English walnut varied from very susceptible to resistant. Japanese walnut was the most resistant.

Hybrids from crosses between species of Juglans also were variable in resistance. Black walnut x Hinds walnut hybrids exhibited more lesions than did black walnut alone. Black walnut x J. microcarpa hybrids also were quite susceptible. English x black walnut hybrids varied from susceptible to resistant. Black walnut x Japanese walnut hybrids were most resistant.

The progeny from 57 parent trees were rated for anthracnose resistance in southern Illinois. Selected families which exhibited high incidence of anthracnose in 1974 also were severely infected in 1975 and 1977. The anthracnose rating system seems consistent enough from year to year to make genetic selection for anthracnose effective. Correlation coefficients for height, diameter, and anthracnose ratings were mostly not significant, suggesting that separate genes affect growth and anthracnose resistance. Our results indicate that anthracnose-resistant families are not necessarily rapid growing, but the faster growing families tend to be more resistant.

FERTILIZATION

Supplementing the soil nutrients with N and NPK significantly stimulated the growth of young black walnut trees in plantations. Surface applications at the rate of 6 pounds of N/1000 square feet increased tree height by 62% over that of untreated trees. Fertilization with N and NPK also affected anthracnose ratings: trees treated with nitrogen alone had substantially less anthracnose than trees that had been treated with NPK or those receiving no treatment. The effects were most evident during the early portion of the growing season.

CONTROL BY FUNGICIDES

Between 1973 and 1976, eight commercially available fungicides were applied to established black walnut plantations or to trees in natural stands. In seven of eight tests, benomyl (Benlate, DuPont) was more effective than other materials tested. Since anthracnose infections can originate at any time between May 15 and October 15, the timing of fungicide sprays presents a problem. Four sprays at 3-week intervals starting May 15 gave excellent control. The use of two sprays, with the first applied in the last week of May to inhibit the primary infection by ascospores and the second applied in the first week of July to inhibit secondary infection by conidia, appears to be a practical alternative.

From 1973 through 1977 walnut anthracnose probably received more attention than did any other foliar disease of a deciduous tree species. We have carefully defined the variability of the causal agent and the environmental factors that regulate its growth and reproductive potentials. We can describe more fully the conditions that influence infection of the host by the pathogen and know how the environment regulates the general course of epidemiology. Control of the disease with protective fungicides is possible.

Still, we have much to learn before we can satisfactorily answer inquiries from the layman concerning disease control. We do not know how damaging the disease is to plant growth or nut production. We hesitate to recommend protective fungicide applications and/or the addition of fertilizers to mature trees when we do not know the risk-benefit ratio and whether the treatments are economically feasible. I am pleased that a plant pathologist has been transferred to the Carbondale laboratory and that a substantial portion of his time will be spent on research on this disease. Additional knowledge is needed and can be justified.

GROUP DISCUSSION

Payne: You said you don't know the effects of nitrogen on trees. Well, walnut trees can't fix nitrogen, so when they're producing a nut crop there is a total nitrogen drain all the time. You mean you don't recommend yearly application?

Neely: No, no, no. By that I was referring to nitrogen and its relationship to walnut anthracnose. Not the relationship between nitrogen and tree growth.

Smythe: Can you tie the variability of resistance of English walnut to some known factor such as site or seed source?

Neely: No, I am afraid not. We just haven't done enough work in this area. We do feel that our inoculation technique and our method of taking readings on infected trees are sufficiently good to use to obtain that kind of information.

Green: Do you get lesions on the current season's shoot growth as well as on the leaf lamina?

Neely: Unlike oak and sycamore anthracnose we have not been able to find such shoot lesions on walnut in Illinois. Others have described this on walnut, however.

XYLOSANDRUS GERMANUS (BLANDF.) (COLEOPTERA: SCOLYTIDAE), A NEW PEST OF BLACK WALNUT: A REVIEW OF ITS DISTRIBUTION, HOST PLANTS, AND ENVIRONMENTAL CONDITIONS OF ATTACK

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ABSTRACT.--In southern Illinois Xylosandrus germanus has recently been reported attacking black walnut, Juglans nigra L., that were infected with a Fusarium canker. X. germanus was introduced to the United States from Japan in 1932. It now occurs throughout S.E. Asia, Germany, and the northeastern United States and has a worldwide host plant range of 34 different genera. X. germanus is capable of attacking live trees under certain ecological conditions and also of transmitting disease.

The ambrosia beetle, Xylosandrus germanus (Blandf.) (Coleoptera: Scolytidae), is a recently discovered pest of black walnut (Kessler 1974). It was found on black walnut in association with stem-girdling cankers, caused by Fusarium spp., in a 6- to 7-year old walnut plantation in southern Illinois. Tree damage included cankers, top dieback, and resprouting from the base (fig. 1). Kessler (1974) speculated that the dieback problem in black walnut was due to a disease/insect association between two species of Fusarium (F. lateritium Nees and F. oxysporum Schlecht.) and X. germanus. Since then, I have found the ambrosia beetle/Fusarium complex causing similar damage to young black walnut plantations in Indiana and North Carolina.

DISTRIBUTION

X. germanus was introduced to the U.S. from Japan. It was first described by Walter F. H. Blandford (1894) as Xyleborus germanus. Reitter (1913) transferred germanus to the newly established genus, Xylosandrus. There are now 24 described species of Xylosandrus in the world, including 3 introduced species in the United States: X. compactus (Eichh.), X. zimmermani (Hopkins), and X. germanus (Bright 1968).

X. germanus occurs throughout Japan, China, Korea, Formosa, and Germany (Wichmann 1955a). X. germanus was first reported in the United States in 1932 on greenhouse-grown grapes (Felt 1932) and is now distributed throughout the Northeastern United States (fig. 2) (Bright 1968, Schneider and Farrier 1969, Kessler 1974).

Figure 1.--Basal trunk sprouts and canker typical of attack by the X. germanus/Fusarium complex. Photo courtesy of Charles E. Cordell, State and Private Forestry, Asheville, North Carolina.

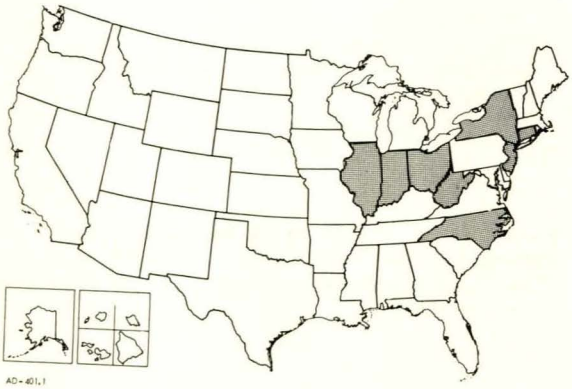

Figure 2.--Range of X. germanus within the continental United States.

HOST PLANTS

X. germanus has host plants in 34 genera throughout its worldwide distribution (table 1). In Germany, Wichmann (1955b) reported Juglans regia L. as a questionable host because no beetles were found. The galleries found in the wood, however, were characteristic of the X. germanus galleries found in other species of trees.

In the United States most species of ambrosia beetles attack woody stumps, logs, wind-broken branches, and dead standing trees. However, in Japan and Germany, as well as in the United States, X. germanus has been reported attacking live trees: red maple, elm, and young black walnut trees in the United States (Hoffmann 1941, Kessler 1974), young red oak trees in Germany (Heidenreich 1960, 1964), and tea bushes in Japan where X. germanus is considered a serious economic pest (Kaneko et al. 1965).

RELATION TO DISEASE-CAUSING ORGANISMS

As well as attacking trees, X. germanus is a disease carrier. Ceratocystis ulmi (Buis.) Moreau, the causal agent of Dutch elm disease, has been found on X. germanus (Collins 1941, Jones and Moses 1943, Batra 1963) and beetles have been proven to transmit it to healthy elm trees (Buchanan 1940, 1941). Also, Kessler (1974) suggested that beetles may carry Fusarium fungi to live walnut from nearby dead wood. In Germany Gauss (1960) noted that dead and dying trees of Acer pseudoplatanus L. had been attacked by X. germanus. At the same time, he noted the presence of Fusarium spp. and Phomopsis spp. The decay fungi, Schizophyllum commune Fr. and Polypora fomentarius (= Fomes fomentarius L. ex Fr.?), have also been found in trees attacked by X. germanus (Heidenreich 1964). No disease association has been reported in Japan.

X. germanus has two small pouches (mycangia), which are formed by the integumental membrane between the first and second segments of the thorax (Francke-Grosmann 1956, 1963, Takagi and Kaneko 1965). These pouches contain the spores of the fungus on which the beetles (adults and larvae) feed. This fungus may also be a disease-causing agent.

The X. germanus female tunnels into the wood, constructs a brood gallery, and lines the walls of the gallery with spores. Then, she carefully tends the developing fungi which is the food for the larvae when they hatch to prevent overgrowth by contamination from undesirable fungi. Eventually, new spores are produced. Movements by the offspring cause their pouches to fill with spores with which to line their own galleries. According to Batra (1967), the primary fungal symbiont of X. germanus is Ambrosiella hartigii Batra, a nondisease-causing fungus. At times, however, spores of other fungi may be picked up and deposited in the mycangia (Batra 1963). Interestingly, the fungal symbiont of X. compactus (Eichh.), a related beetle that attacks 31 plant species in Florida, is Fusarium solani (Mart.) Appel and Wr. (Ngoan et al. 1976).

ENVIRONMENTAL CONDITIONS OF ATTACK

X. germanus most often attacks under the following conditions:

1. The trees are young: 7-year-old red oak in Germany (Heidenreich 1960) and 6- to 7-year-old black walnut in the United States (Kessler 1974).

2. Weather conditions prior to attack are unfavorable to tree growth and conducive to insect outbreak: late spring frosts (Heidenreich 1960), summer droughts (Gauss 1960, Heidenreich 1960, 1964), and mild winters (Gauss 1960).

Table 1.--World List of host Plants of Xylosandrus germanus (Blandf.)

Host	Location	Source
Abies alba Mill.	Germany	Wichmann 1957
Acer pseudoplatanus L.	Germany	Gauss 1960
A. rubrum L.	U.S.	Hoffmann 1941
Alnus incana var. glauca Regel	Japan	Wichmann 1955b
A. glutinosa Gaertn.	Germany	Wichmann 1955b
A. tinctoria glabra Sar.	Japan	Wichmann 1955b
Benzoin thunbergii Sieb. & Zucc.	Japan, Korea, Formosa	Felt 1932
Betula verrucosa Ehrh.	Germany	Wichmann 1955b
Carpinus sp.	Japan	Groschke 1952
C. betulus L.	Germany	Wichmann 1955b
C. laxiflora (Sieb. & Zucc.) Bl.	Japan	Felt 1932
Carya sp.	U.S.	Hoffmann 1941
Castanea crenata Sieb. & Zucc.	Japan	Wichmann 1955b
Cinamomum sp.	S.E. Asia[1/]	Wichmann 1955a
Diospyros sp.	Japan	Ueno 1960
Distylium sp.	S.E. Asia[1/]	Wichmann 1955a
Eurya sp.	S.E. Asia[1/]	Wichmann 1955a
Fagus sp.	U.S.	Hoffmann 1941
F. americana (= grandifolia Ehrh.)	North America	Wichmann 1955b
F. crenata Bl.	Japan	Wichmann 1955b
F. sieboldiana Endl.	Japan	Wichmann 1955b
F. silvatica L.	Germany	Wichmann 1955b
Juglans nigra L.	U.S.	Kessler 1974
J. regia L.	Germany	Wichmann 1955b
Lindera sp.	S.E. Asia[1/]	Wichmann 1955a
Liriodendron tulipifera L.	U.S.	Anderson et al. 1978
Machilus sp.	S.E. Asia[1/]	Wichmann 1955a
Morus sp.	Japan	Groschke 1952
M. abla (sic) L.	Japan	Kaneko 1967
Nyssa aquatica L.	U.S.	Schneider et al. 1969
Picea excelsa L.	Germany	Wichmann 1955b
Pinus resinosa Ait.	U.S.	Buchanan 1941
P. strobus L.	Germany	Wichmann 1955b
Prunus serotina Ehrh.	U.S.	Schneider et al. 1969
Pterocarya rhoifolia Sieb. & Zucc.	Japan	Wichmann 1955b
Quercus paucidendata Franch.	Japan	Wichmann 1955b
Q. pedunculata Ehrh.	Germany	Wichmann 1955b
Q. rubra L.	Germany	Heidenreich 1960
Q. sessiliflora Sm.	Germany	Wichmann 1955b
Rhus sp.	S.E. Asia[1/]	Wichmann 1955a
R. radicans L.	U.S.	Hoffmann 1941
Robinia pseudoacacia L.	Germany	Wichmann 1955b
Shiia sp.	S.E. Asia[1/]	Wichmann 1955a
Styrax japonicum Sieb. & Zucc.	Japan, Korea, Formosa	Felt 1932
Taxodium distichum (L.) Richard	U.S.	Schneider et al. 1969
Thea sp.	Japan	Groschke 1952
Toxicodendron sp.	U.S.	Bright 1968
Tsuga sp.	U.S.	Bright 1968
Ulmus americana L.	U.S.	Buchanan 1940
U. effusa Willd.	Germany	Wichmann 1955b
Vitis sp.	U.S.	Felt 1932

[1/]S.E. Asia = China, Japan, Korea, Formosa.

3. High beetle populations exist in the vicinity of the attacked trees on freshly cut stumps, logs, or branches (Heidenreich 1960, 1964, Hoffmann 1941, Kessler 1974).

4. Moisture content of the attacked wood and relative humidity of the air are high (Hoffmann 1941, Groschke 1953, Heidenreich 1960).

IMPORTANCE TO BLACK WALNUT

Fisher et al. (1953) state that ambrosia beetles, in general, are not primarily responsible for the death of trees, even in the tropics where they cause considerable damage. Instead, their economic importance lies in the degrade of sawn timber that results from their galleries and staining of the wood. For black walnut the primary importance lies in the extra time, labor, and money required to prune out dead tops and to remove all but one healthy sprout from a tree affected by the Fusarium/X. germanus complex. In addition, several years of growth time may be lost.

Studies are continuing on X. germanus and its relations to Fusarium and to black walnut. Meanwhile, control measures suggested by Kessler (1974) are still applicable: remove pruned branches or dead trees from the vicinity of the plantation to prevent a beetle population build-up.

ACKNOWLEDGMENTS

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GROUP DISCUSSION

LaMadeleine: You mentioned that you could not find any more ambrosia beetles here in Illinois so you went to North Carolina. What is your feeling on the impact of this dieback, Barb?

Weber: In North Carolina, I did a survey and in one year 30 percent of the trees suffered from dieback, apparently from the Fusarium/ambrosia beetle problem. The trees themselves die back to the ground or a few inches above the ground. The walnut grower must go in and cut the dead tree back all the way to the ground and leave one of the sprouts. The sprouts are usually fairly healthy; they don't seem to be attacked later on. And so the impact would be the fact that you are losing growth and the fact that the grower must spend extra time pruning and making sure that all the diseased trees are removed from the area.

LaMadeleine: You know of a couple of plantations--are you finding it in more and more areas?

Weber: The number of plantations now is probably half a dozen, most of them in Indiana. I have recently found a population of the ambrosia beetle here again in southern Illinois. North Carolina is also a location. Ken found Fusarium in Iowa and Missouri but did not see the ambrosia beetle. One of the major parts of my study is to try to determine if X. germanus really is carrying the Fusarium fungus into these trees or what the exact association is.

Payne: Does Fusarium also cause the wood to stain blue?

Weber: Fusarium causes a brown stain.

Shigo: Regarding this German work, I would need a lot of convincing to believe that Shizophyllum commune was a direct associate with your beetle, because it is such an aggressive fungus. It will come in any place there is dead wood. I know you cited it as German work, but I would think carefully on that one to really show that it was a direct associate.

Weber: The Germans state that they found the fungus and the beetles at the same time and imply an association but give no direct proof.

THE ETIOLOGY, DISTRIBUTION, EPIDEMIOLOGY, HISTOLOGY AND IMPACT OF BUTTERNUT CANKER IN WISCONSIN

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ABSTRACT.--A canker disease of butternut which was first reported in Wisconsin in 1967 occurs throughout much of the tree's natural range and is a serious threat to the survival of the species. Trees of all age and size classes, regardless of site conditions, are afflicted by multiple cankers which occur on all above-ground woody plant parts. The causal agent of the disease is a fungus, Sirococcus species. Although the fungus has occasionally been found associated with small cankers on black walnut growing in mixed stands with butternut, artificial inoculations in the greenhouse indicate that the fungus is weakly pathogenic to black walnut.

Widespread dying of butternut first was reported in Wisconsin in 1967 (2, 7). The number and extent of the diseased areas as well as the deterioration of the dead trees indicated that the disease had been active for several years. Canker-dieback since has been found throughout the range of butternut (1, 11), and the fungus pathogen has been isolated from diseased specimens collected in Indiana, Iowa, Michigan, Minnesota, Missouri, Pennsylvania and Wisconsin. A "Pest Alert" announcing "butternut decline" was issued in 1976 (12).

Although butternut is a minor species in Wisconsin (9), quality butternut is second only to walnut in economic value (5). In fact, Wisconsin ranks second in the amount of butternut found in the United States and is a major producer of butternut lumber for furniture, cabinets, and fine woodworking (8).

In the past, butternut has suffered from few diseases (3) or insect pests. Now, however, it appears that canker is a potential threat to butternut throughout its natural range (10, 1). In North and South Carolina, butternut has been essentially eliminated by the disease (1). Likewise, in southwestern Wisconsin, many stands have been decimated and butternut is a "threatened species". In disease survey plots, as many as 80% of butternuts were cankered and 32% were dead (6). In contrast, in several counties in northeastern Wisconsin, no cankered trees were discovered. At first, no cankered butternuts were reported in the northern states of New Hampshire and Vermont (1), but recent communications indicate that the disease is present.

In Wisconsin, cankers were found on all woody parts of diseased butternuts, including twigs, branches, stem and buttress roots. Stem cankers, usually many per tree, both separate and coalescing, occurred on all sides of the trunk, especially the lower portion. Trees of all ages and sizes, growing in mixed and relatively pure stands, on dry, infertile ridgetops

or moist, fertile bottomlands were cankered. Infected trees occurred in local pockets or over extensive areas. Among the severely cankered butternuts, occasional butternuts appeared healthy. Whether these trees are resistant or escape must be determined. However, incipient cankers can be overlooked unless bark is removed to reveal the darkened wood beneath. So far, in one study plot, small twig and branch cankers have been detected on a few black walnuts growing in mixed stands with severely infected butternuts.

Diagnostic symptoms of butternut canker include discrete, elliptical cankers involving the bark and wood of twigs, branches, stems and even roots (4). Young cankers commonly originate at leaf scars, other natural openings, such as lenticels and stomates, buds, bark wounds including insect wounds, natural bark cracks, and occasionally at points apparently free of any injury. Older cankers on trunks are large, open or partly covered by shredded bark, vertically oriented and perennial. Some stem cankers have progressed for many years (up to 13 years) as evidenced by successive layers of lateral callus or by differences in annual ring counts. In many cases, their origin is unknown, but adventitious buds are present in the centers of some cankers.

Peeling the bark from trunks may disclose small, local areas of brown, inner bark, and later, black wood of undetected incipient cankers. Older cankers often bear shredded bark, frequently are bordered by callus layers, and may coalesce to girdle and kill large branches or stems. Branch suckers and trunk sprouts frequently develop below the girdled portion, are infected readily, and die shortly thereafter. Seasonal sprouts become infected in the fall soon after leaf fall, but remain symptomless during the winter. In the early spring, before budbreak (April, 1978), tiny, round, chocolate-brown lesions develop around lenticels and small, irregular lesions develop at leaf scars. Initially, only the outer bark is infected, but soon the wood is invaded. Within a couple of weeks, the outer bark loosens, blisters, ruptures, and rolls back exposing masses of black hyphal pegs arising from a thin black fungus stroma. Under moist conditions, millions of conidia are extruded in countless colorless cirri (tendrils) from pycnidia borne in the stroma among the hyphal pegs.

In infected suckers, twigs, and branches, walls of bark cells are degraded (thinned), macerated, and rapidly disintegrated completely, leaving only a dark brown, gummy residue which gives rise to a brown exudate. The fungus penetrates the cell walls intracellularly and progresses through the ray parenchyma into the xylem. It then spreads into the longitudinal parenchyma and eventually into other bark and wood tissues. In spring, an inky-black, watery exudate issues from canker fissures; later, in summer, sooty-black patches remain. Eventually, infected butternuts die. Little or no regeneration of butternut occurs in diseased areas (6).

Under the outer bark, the causal fungus (coded BN-5, and tentatively identified as a new Sirococcus species) forms a thin, black stroma from which hyphal pegs arise lifting the outermost bark layer (4). Among the pegs are globose to flattened, single or confluent pycnidia in which short conidiophores line the inner pycnidial surface and bear hyaline, two-celled, fusiform conidia. Tan, sticky spore masses are extruded as "globs" or as cirri, and spores are disseminated by splashing or blowing rain or mist (4, 11). The causal fungus is readily isolated on common media from both bark and wood, grows best at 24-28° C in light or dark, forms hyphal pegs and pycnidia in culture, and sporulates profusely in the light or dark especially on thin, drying agar cultures. Inoculations of fresh wounds with mycelium, spore masses, or spore suspensions incite cankers on branches and stems of butternut and black walnut (J. nigra L.) seedlings and saplings. Young, succulent tissue is especially susceptible. Stem cankers develop at 16, 20, 24, and 28° C, and often kill butternut seedlings within 2 weeks especially at 16 and 20° C. Inoculations of young, succulent, nonwounded butternut seedlings with conidia suspensions followed by 48 hours of misting incite necrotic lesions on leaves which quickly droop, wither, and abscise before or after the fungus invades stem tissue.

So far, the disease has been detected infrequently on black walnuts growing in mixed stands with severely infected butternuts, but artificial inoculations induce progressive and killing cankers on young black walnut seedlings. On inoculated walnut saplings, stem cankers progress slowly, and many appear to be walled-off by callus layers bordering the canker. Hopefully, black walnut will prove to be resistant. Otherwise, the increasing number of walnut plantings in the central states would be in grave danger.

Meanwhile, disease studies continue, while detection and appraisal surveys by state and federal agencies seek to determine the distribution and impact of butternut canker on forest stands and plantings. The formulation of effective control measures must await further information. However, black walnut should not be planted in close association with infected butternuts. In mixed stands, cankered butternuts should be removed immediately.

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GROUP DISCUSSION

Nicholls: What causes the exudate from the cankers?

Jutte: I think it is the remains of cell walls. There are a lot of extractives in the wood of walnut and butternut that occur in the cell walls. Also we must not forget the lignins which are degraded. The lignin residues plus the resins constitute much of the black material.

Kuntz: In very young cankers some of the exudate occurs as droplets of liquid. Dr. Jutte feels that this liquid may be produced as the result of tissue maceration by enzymatic action.

Shigo: Exudation is a common early symptom of many cankers. Nectria cankers can have the same thing.

A lot of cankers originate at insect punctures. Cricket punctures on maple often have a black spot as an early symptom.

Kuntz: I think it's not an accumulation of dark spores as we originally thought. I think it's a host reaction to injury.

Shigo: The Sirococcus fungus seems to do so many things that it worries me. I wonder if you may not have a complex of several organisms responsible for this disease. I would be very interested in seeing what the differences are in the histopathology of the twig and stem cankers. You said that one seemed to be walled off while the other was not. Another thing that concerns me is that you have a fungus that kills tissue and also causes cell wall dissolution. It's possible but it raises the question of whether several organisms could be involved.

Kuntz: In the early stages of canker development only Sirococcus is isolated. Succulent tissue, particularly at times when trees are either going into or out of dormancy, is very susceptible to infection by this fungus. In the greenhouse, seedlings are killed in ten days after inoculation with the fungus. They are girdled, necrotic, wilted and dead.

Shigo: In some ways this disease is similar to chestnut blight.

Kuntz: We draw the same comparison and, of course, some people think that chestnut blight has some characteristics of a vascular wilt as well.

Neely: The term hyphal peg intriques me. Normally something like that, as with oak wilt, is called a pressure cushion. The sycamore anthracnose fungus when it fruits on twigs produces what I call a pressure cushion; it is very similar to your hyphal peg and the anthracnose fungus also produces pycnidial cavities in exactly the same manner as what you are showing me here.

Kuntz: The Sirococcus hyphal peg is not a pressure cushion.

Neely: Why is it not?

Kuntz: It's a peg. It's like your finger--like a cone. It's function is to lift the outer bark.

Nair: We have not found spores developing on the hyphal pegs.

BUTTERNUT CANKER

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ABSTRACT.--Butternut (Juglans cinerea L.) is declining throughout much of its range primarily due to a new canker disease caused by a fungus species in the genus Sirococcus. The canker does not appear to pose a serious threat to black walnut (Juglans nigra L.), a close relative of butternut. Butternut trees are killed by multiple cankering of branches and tree trunks. The dying portions of the tree often are colonized by a secondary-invading fungus, Melanconis juglandis. In culture, benomyl showed the best activity against the Sirococcus fungus at low concentrations (0.1 ppm), chlorothalonil was effective at higher concentrations (1 ppm), and maneb was ineffective at all concentrations tested. Fungicide control will not be economically feasible except possibly in nurseries and plantations. However, cultural and genetic controls may be possible.

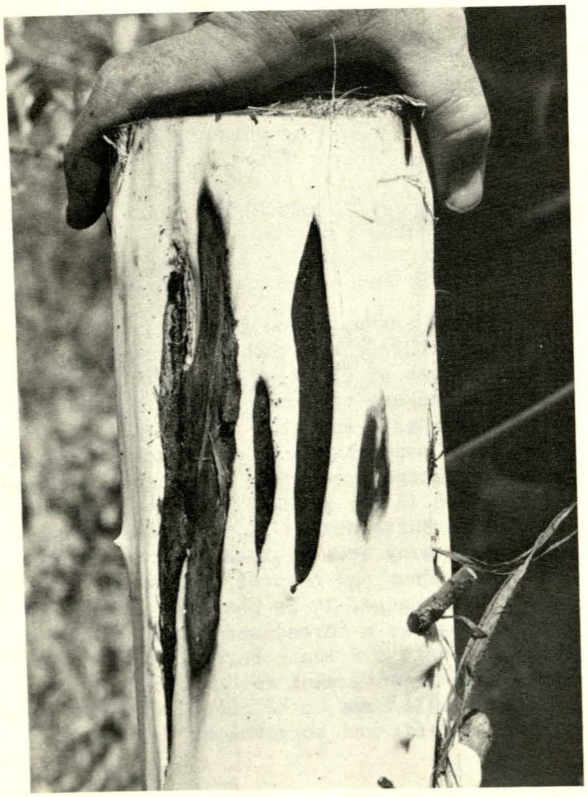
Butternut, also called white walnut, is closely related to black walnut. Although butternut wood is light, it can be stained to look like black walnut. The wood has many uses including furniture, cabinets, fine woodwork, and paneling. In fact, in many areas where quality butternut wood is available, it is second in economic value only to black walnut.

Butternut is a minor species in the mesophytic climax forests on rich moist sites throughout the northern two-thirds of the Eastern United States. Nowhere is butternut common and its frequency is declining primarily due to a serious canker disease first reported in 1967. Except for this canker, butternut does not seem to be susceptible to any serious disease. Presumably, if the canker disease could be controlled, butternut could become a more prevalent timber and nut-producing species. Butternut, if grown canker-free, could be planted in plantations and handled similar to black walnut. In fact, butternut has some advantages over black walnut: (1) it is less demanding in its site requirements and can be grown on poorer soils and (2) it is more cold resistant and can be grown farther north.

Recent surveys show that butternut canker is present throughout much of the butternut range. Trees of all ages are infected and cause multiple cankers to form on branches and trunks which together eventually girdle and kill the trees. In many cases, it may take several years before infected trees die. The canker, caused by a fungus in the genus Sirococcus, has already eliminated butternut as an important forest species in many areas. Because it is being eliminated from the natural ecosystem throughout much of its range, it is possible that butternut soon may become a threatened species (from U.S.F.S. State & Private Forestry Survey data). Thus, forest management recommendations for butternut will have to be carefully considered for the benefit and survival of this species.

DISSECTION OF BUTTERNUT TREES

To obtain some basic information on the Sirococcus canker, 18 butternut trees were dissected and evaluated in La Crosse, Dane, and Dunn Counties in Wisconsin between 1976 and 1978. The bark was peeled off trees to reveal the dark-colored cankers, which were highly visible on the light-colored wood (Figure 1). Then, the following data were recorded: tree height and age; percent crown dead; number of healthy, cankered, or dead branches; number of trunk cankers; age of oldest canker; average length and width of cankers; and the number of cankers associated with leaf scars or buds. The information obtained was useful in characterizing the frequency and distribution of cankers. The results clearly revealed that butternut trees contain multiple cankers on their branches and trunks which eventually girdle and kill them regardless of whether they are growing on good or poor sites.



Trunk Cankers.--Infected butternut trees had numerous trunk cankers of different ages, many of which had coalesced. As many as 109 trunk cankers were observed on one tree but most infected trees averaged about 42 trunk cankers. Cankers were found on dissected trees ranging from 12- to 40-years old and from 10- to 53-feet-tall. Cankers were dark brown to black, elongate, and irregularly oriented on the trunk (Figure 1). Stem girdling or near girdling required the coalescence of several cankers. Cankers appeared to be perennial. Some cankers might have been inactive because they had successive vigorous callus growth around their margins, sometimes completely covering cankers. Canker ages ranged from 1 to 12 years, the latter with an origin of 1966 or about 1 year before the disease was first reported in Wisconsin. Most cankers were associated with adventitious buds, which probably serve as infection courts. Peeling the bark from the trunks was necessary to find the younger cankers but many older underlying cankers could easily be detected before peeling by sooty bark patches and loose, shredded bark resulting from an inky-black, watery exudate. Most infected trees had a partially dead crown but some infected trees had healthy-looking crowns.

Figure 1.--Multiple dark-colored cankers are easily detected on infected butternut trees when bark is removed.

Table 1.--Dissection results of seven butternut trees in Blue Mounds State Park, Dane County, Wisconsin, May 26, 1976

Tree number	D.b.h.	Height	Age	Crown dead	Healthy branches	Cankered branches	Dead branches	Trunk cankers	Age of oldest canker examined
	Inches	*Feet*	*Years*	*Percent*	*Number*	*Number*	*Number*	*Number*	*Years*
1	2	10	20	40	10	20	34	16	4
2	4	22	20	5	13	0	1	0	-
3	3	19	22	50	11	9	6	-[1]	4
4	3	23	--	10	1	18	4	3	4
5	5	25	30	20	--	--	18	21	4
6	8	41	40	40	12	7	14	50+	4
7	6	43	26	50	0	6	3	63	4

[1] Many cankers coalesced.

Crown Symptoms and Branch Cankers.--Crown dieback was associated with extensive trunk cankering, branch cankering, or both and ranged from 0 to 75 percent (Tables 1 & 2). Most branch cankers originated at leaf scars or buds through which infection frequently occurred (Table 3). Young branch cankers were slightly sunken, elongate, and dark brown to black. Numerous branch cankers can kill branches and the epicormic sprouts that are produced when portions of the tree dies. The dying portions of the tree were often rapidly colonized by a secondary invading fungus, Melanconis juglandis.

One of the dissected trees had only one trunk canker but had many new branch cankers near the top of the tree indicating a major new infection of a previously healthy tree (Table 4).

Root Systems.--Roots of five trees were examined. Although cankers on some trees occurred on exposed buttress roots, infection did not appear to affect the rest of the root system. The fungus did not seem to be transmitted between trees through the root systems.

Table 3.--Average trunk and branch canker lengths and widths and their association with leaf scars or buds on three butternut trees examined in La Crosse and Dunn Counties, Wisconsin, spring 1978.

Tree[1]	Canker location	Average canker length	Average canker width	Cankers associated with leaf scars or buds
Number		*mm*	*mm*	*Percent*
	La Crosse County			
1	Trunk	158	31	70
	Branches	38	8	50
2	Trunk	166	27	80
	Branches	73	14	70
3	Trunk	82	23	--
	Branches	66	17	--
	Dunn County			
4	Trunk	--	--	--
	Branches	45	7	30
5	Trunk	108	11	--
	Branches	53	4	--
6	Trunk	173	26	50
	Branches	43	7	60

[1] Ten trunk and 10 branch cankers were examined on each tree.

Table 2.--Dissection results of five butternut trees on the Coulee Experimental Forest, La Crosse County, Wisconsin, May 18, 1977

Tree number	D.b.h.	Height	Age	Crown dead	Healthy branches	Cankered branches	Dead branches	Trunk cankers	Age of oldest canker examined	Average cankers/ branch
	Inches	*Feet*	*Years*	*Percent*	*Number*	*Number*	*Number*	*Number*	*Years*	*Number*
1	4.7	25	21	10	6	8	9	33	5	5
2	3.2	21	15	75	0	10	5	46	4	9
3	4.2	26	20	60	1	19	10	57	6	6
4	3.8	23	20	20	6	20	21	39	6	2
5	4.7	26	16	0	12	0	4	0	-	0

Table 4.--Dissection results of three butternut trees in La Crosse and Dunn Counties, Wisconsin, spring, 1978

Tree	D.b.h.	Height	Age	Trunk cankers	Age of oldest canker examined
	Inches	*Feet*	*Years*	*Number*	*Years*
La Crosse County					
1[1]	2.5	23	13	36	5
2	2.2	19	12	33	5
3	4.4	29	23	109	7
Dunn County					
4	5.0	49	24	1[2]	5
5	4.8	47	26	52	11
6	8.2	53	32	73	12

[1] This tree appeared to be resistant because many cankers were walled off.

[2] Many small cankers present near top of tree on small branches.

Associated Insects.--Several unidentified insect larvae were found under the bark of some trees and discolored tree tissue similar to that caused by the fungus was found around them. Five isolations were made from the tissue to determine if this insect might be a vector or to see if the fungus might have gained entrance to the trees through wounds made by the insect. However, the fungus was not recovered from the discolored tissue and it is now believed that the tissue damage was caused by insect activity alone. Other insects associated with cankered trees were Acrobasis bud borers, weevils, spring tails, and thrips. Wounds caused by insects may serve as infection courts, but this was not adequately documented in this study.

The Sirococcus fungus produces spores in a sticky matrix and the cankers themselves secrete a material that oozes out onto the bark of trees. Insects may be attracted to this secretion and then transmit spores to healthy trees.

Resistance to Butternut Canker.--Two dissected butternut trees had no cankers even though they were surrounded by heavily infected trees (Tables 1 & 2). A third tree had 36 trunk cankers, but most of the cankers had healed over indicating some resistance (Table 4). These examples, along with other similar field observations, indicates that some trees may be genetically resistant to the disease. In this study, one black walnut was dissected and several others evaluated, but no infections were observed even where they were associated with heavily infected butternut. Other investigators have occasionally detected a few cankers on black walnut saplings, primarily those under stress. However, the canker does not seem to pose a serious threat to black walnut because black walnut appears to be highly resistant to the pathogen.

FUNGUS BIOLOGY

Spore release and dissemination.--In 1976 and 1977 vaseline-coated microscope slide spore traps were placed beneath and various distances from infected butternut trees in La Crosse and Dane Counties in Wisconsin. In addition, in 1977 spore traps were placed under butternut trees with dying branches in Marinette County, Wisconsin, where butternut canker has never been found. Traps were changed weekly from April to October and at irregular intervals from November through March. All Sirococcus spores were counted with a microscope at 400X on three vertical strips on each slide to determine the number of spores trapped and duration of spore release during the year. Weather and host phenological data were also obtained at each site.

Spores were produced from early April until late October in both 1976 and 1977 (Figures 2 & 3). Germinating spores were found the weeks of May 10, July 26, and August 23, 1976, which may indicate infections periods. Because no spores were found on traps during weeks with no rainfall, rainfall must be necessary for spore release. Spores were found on the furthest traps from an infected tree, 150 feet, so spores can be rainsplash- and wind-disseminated at least that far.

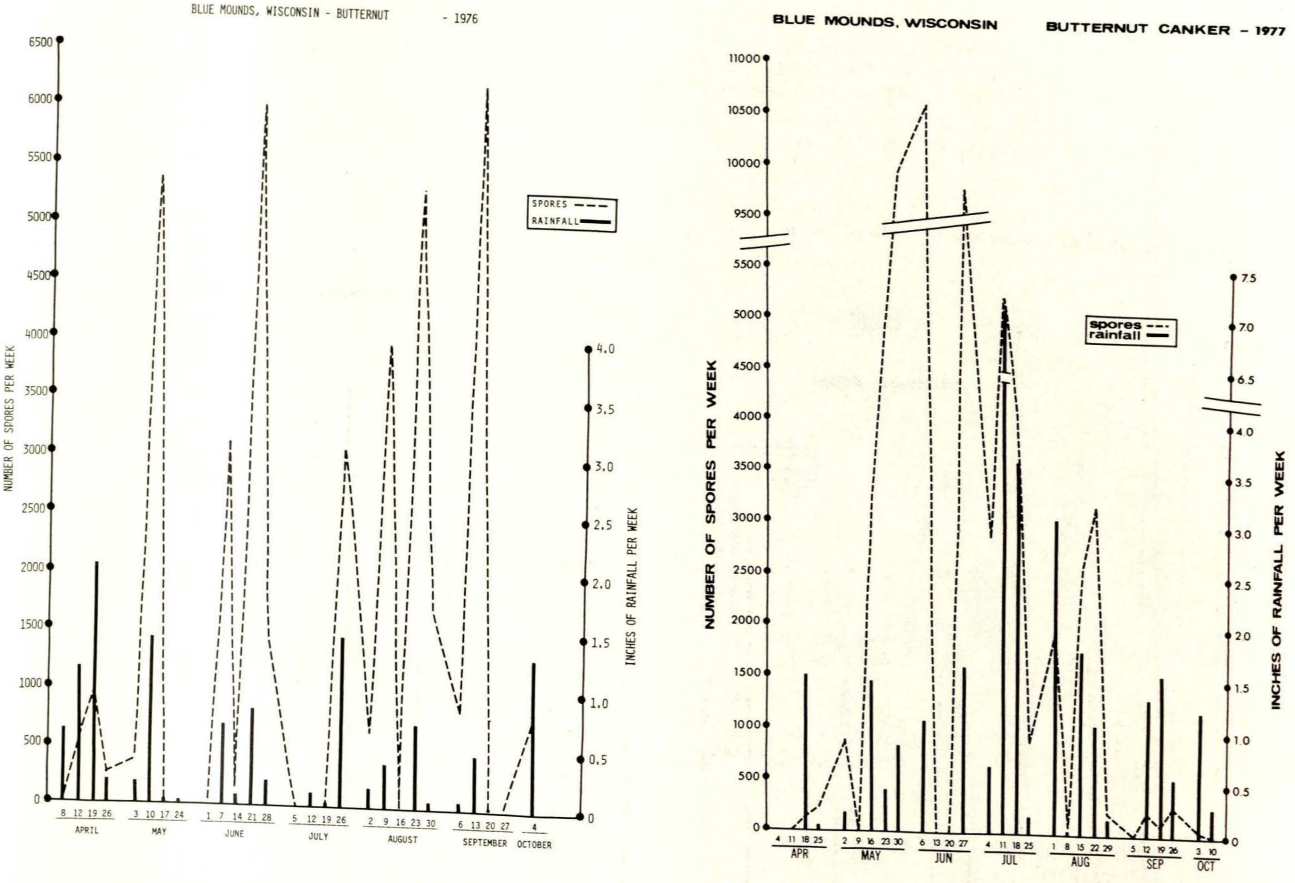


Figure 2.--Weekly butternut canker spore release and rainfall, Blue Mounds State Park, Dane County, Wisconsin, 1976 and 1977.

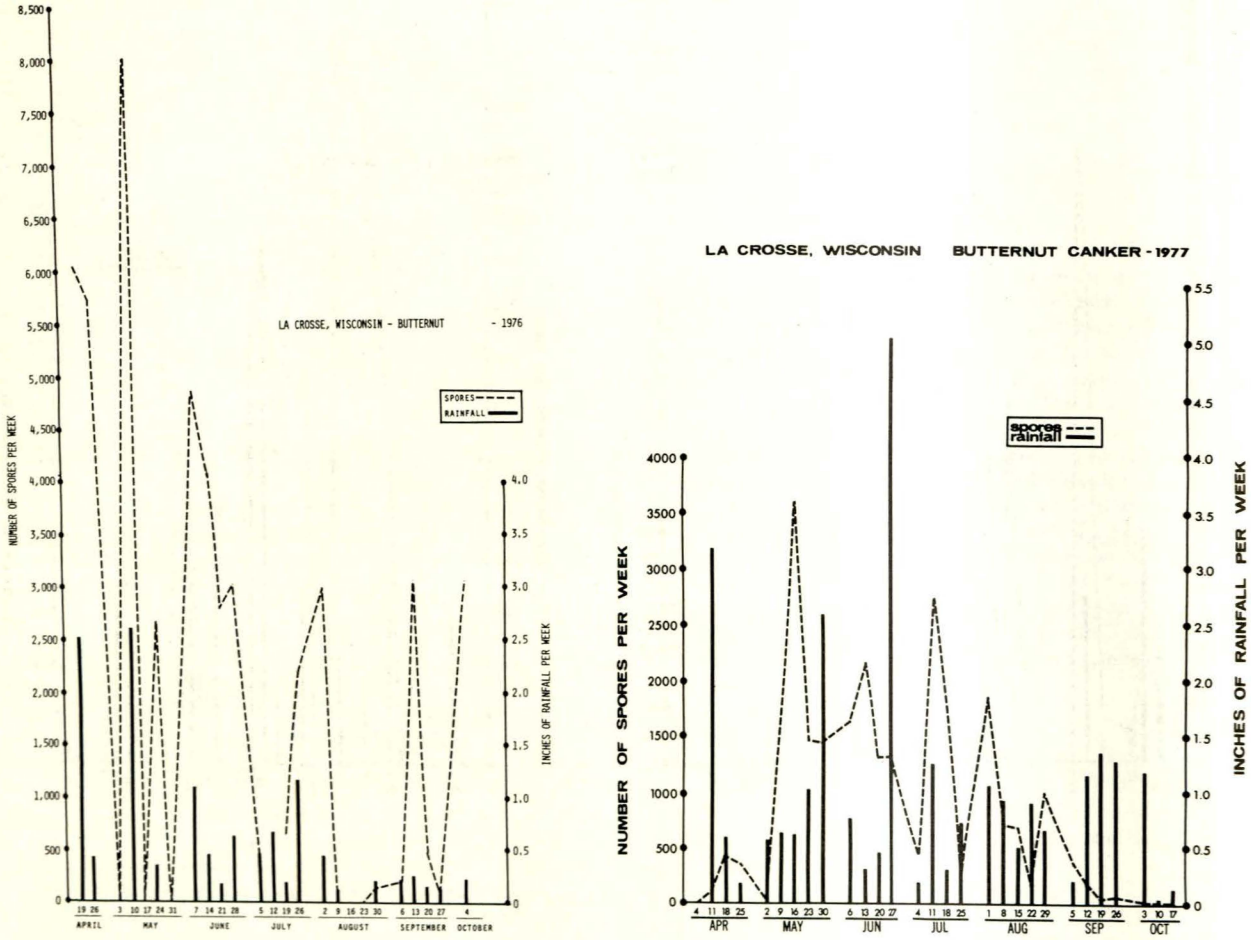


Figure 3.--Weekly butternut canker spore release and rainfall, Coulee Experimental Forest, La Crosse, Wisconsin, 1976 and 1977.

Despite the much-below normal 1976 rainfall, the total number of butternut canker spores trapped at two locations in southern Wisconsin were as follows:

Blue Mounds State Park

Spore trap location	Spore *Number*	Rainfall *Inches*
1. Under infected tree	35,159	12.34
2. Directly under cankers	3,880	
3. Directly under cankers	958	
4. In open, 18 feet from nearest infected tree	436	
Total	40,433	

Coulee Experimental Forest

1. Under infected tree	40,325	12.09
2. Directly under cankers	7,974	
3. Directly under cankers	1,696	
4. In open, 12 feet from nearest infected tree	377	
Total	50,372	

Rainfall was close to normal in 1977 and spore production and infection continued at a high level. The total number of butternut canker spores trapped in 1977 at the same 2 locations were as follows:

Blue Mounds State Park

Spore trap location	Spore *Number*	Rainfall *Inches*
1. Under infected tree	524	29.62
2. Under infected tree	60,925	
3. In open, 18 feet from nearest infected tree	54	
4. In open, 150 feet from nearest infected tree	13	
Total	61,516	

Coulee Experimental Forest

1. Under infected tree	5,067	27.73
2. Under infected tree	20,266	
3. In open, 12 feet from nearest infected tree	403	
4. In edge of red pine plantation, 35 feet from nearest infected tree	176	
Total	25,912	

The dying portions of many butternut trees were rapidly colonized by a secondary-invading fungus, Melanconis juglandis (E. & E.) Graves. The spores of the imperfect stage of this fungus, M. oblongum, were also counted on the spore traps because of its close association and possible confusion with butternut canker. Major M. oblongum spore production occurred in May, June, and July, although some spores were released throughout the April to October period (Figures 4 & 5). Rainfall was also necessary for M. oblongum spore release.

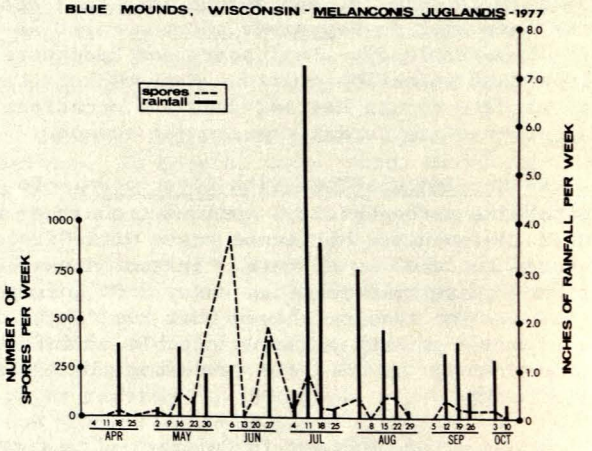


Figure 4.--Weekly Melanconis juglandis spore release and rainfall, Blue Mounds State Park, Dane County, Wisconsin, 1977.

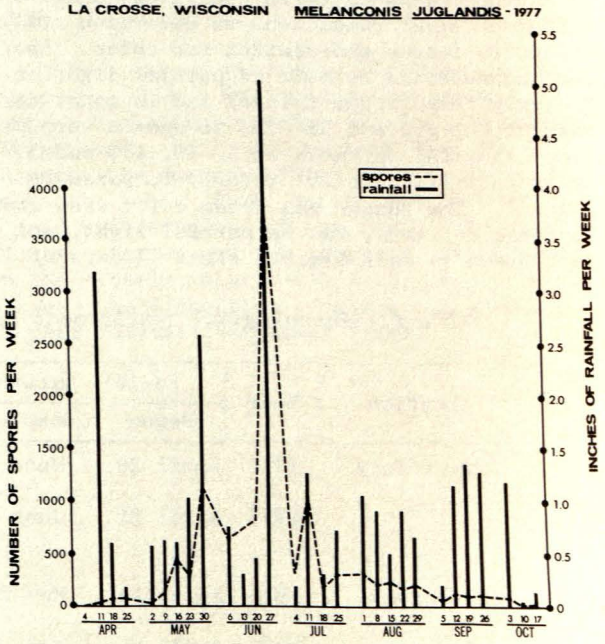


Figure 5.--Weekly Melanconis juglandis spore release and rainfall, Coulee Experimental Forest, La Crosse County, Wisconsin, 1977.

As expected, no Sirococcus spores were trapped in Marinette County where the canker has not yet been found. However, M. oblongum spores were trapped indicating its presence on dead branches of butternut trees in that area.

Phenology of Butternut.--Information on the phenological development of butternut is important for understanding the relation between time of host susceptibility and various stages of the fungus life cycle. Petiole growth began as early as April 11, leaflet growth ended as late as June 28, and autumn leaf fall occurred the last week in September and the first week in October (Table 5). Leaf scars and buds were important infection courts. Many cankers secreted an exudate during May and June and occasionally at other times during the growing season.

Butternut Inoculations with Sirococcus.--To determine pathogenicity, various techniques were used to inoculate butternut trees with Sirococcus spores produced in culture. Infection was confirmed by reisolating the fungus from infected tissue. The results showed that the fungus is a vigorous primary pathogen capable of infecting trees through wounded and unwounded plant tissue (Table 6).

Sirococcus Growth Study in Culture.--The fungus was incubated in vitro at 5, 10, 15, 20, 25, 30, and 35° C without light on potato dextrose agar to determine its optimum growth temperature. Optimum fungus growth occurred at about 30° C. Some growth did occur at 5° C, but none at 35°. In another test, cultures were grown under different light conditions to determine its effect on fungus sporulation and color. Spores were produced in culture in partial light at 20° C. (only temperature tested) and in total darkness at 20, 25, and 30° C. No spores were produced in total darkness at 5, 10, 15, and 35° C or in full light at 20° C (only temperature tested). The fungus was cream color when grown in total darkness, tan in partial light, and dark brown in full light. After 17 days of

Table 6.--Susceptibility of butternut seedlings to butternut canker fungus in greenhouse inoculation tests

(In numbers)

Treatment	Trees in test	Trees[1] infected	Trees healthy
Spores applied by needle to wounds on stems and petioles	4	2	2
Spore suspension poured on leaves and stems, trees in plastic bags for 10 days[2]	3	3	0
Spore suspension poured on leaves and stems, scalpel wounds made, trees in plastic bags for 10 days	9	7	2
Trees wounded with scalpel, spore suspension applied to wound	4	0	4
Petiole bent to make small wound, spore suspension applied to wound	3	2	1
Total	23	14	9
Checks - Wounded	3	0	3
Unwounded	2	0	2
Total	5	0	5

[1] Confirmed by isolating fungus from infected tissue.

[2] Plastic bags were used to cover trees and provide optimum conditions for infection.

Table 5.--Phenological development of butternut in southern Wisconsin, 1976-1977

Location	Year	Petiole growth		Leaflet growth		Autumn defoliation completed
		Begun	Completed	Begun	Completed	
Dane County	1976	April 26	June 7	May 3	June 28	October 5
	1977	April 11	June 6	April 18	June 13	September 26
La Crosse County	1976	April 19	May 24	May 3	June 7	October 5
	1977	April 11	June 6	April 18	June 13	September 26

incubation, the fungus had an average diameter of 37 mm in total darkness, 27 mm in partial light, and 21 mm in full light. Only one Wisconsin isolate was used in this test, but the results show that temperature and light greatly affect fungus behavior. Therefore, researchers should document their notes carefully so that results can be accurately compared between workers.

Fungicide Tests.--Three fungicides were tested. Benomyl showed the best activity against the fungus at a low fungicide concentration (0.1 ppm), chlorothalonil was effective at a higher concentration (1 ppm), and maneb was ineffective at all concentrations tested (Table 7). Thus, at least two fungicides can be used for field testing in nurseries and plantations, if necessary. Unfortunately, it is unlikely that fungicides can economically be used to control this fungus because butternut trees are usually so dispersed and are so seldomly planted in plantations.

Table 7.--Activity of three different fungicides on butternut canker in vitro

($\bar{X}$ fungus growth, mm)

Treatment[1]	Fungicide concentration (ppm)				
	1	0.5	0.25	0.1	0
Maneb	21.8	25.0	22.7	24.3	--
Chlorothalonil	0	4.6	7.3	11.8	--
Benomyl	0	0	0	0	--
Check	--	--	--	--	29.8

[1] Final readings were made after fungus cultures were incubated for 9 days at 20° C.

DISCUSSION

Forest managers who are concerned about Sirococcus fungus need to know how best to manage their stands that contain butternut. Perhaps hazard zones of different harvest priority could be set up to salvage trees before they die and become useless. To do this we must know the detailed distribution and rate of spread of the canker disease. If it is determined that butternut is a threatened species with the potential of it becoming an endangered species, totally different management prescriptions will have to be made with a prime objective being species survival.

Control of butternut canker will be extremely difficult, if not impossible. It is doubtful that chemical control will be economically practical except possibly in high value plantations and nurseries. Cultural controls may be useful in reducing the spread of the disease. For example, infected logs should not be shipped to mills in areas where butternut trees are healthy and the canker has not been found. Spores from such logs could serve as an inoculum source for adjacent healthy trees. Another useful practice is to prevent logging wounds during timber harvesting in areas where butternut are growing because wounds provide entry courts for the fungus.

Genetic resistance to the disease appears possible. In several areas where heavy mortality has occurred, a few apparently resistant (or possibly escape) trees have been found. These trees should be tested to see if they are truly resistant. If they are, seed can be collected from them and then the seedlings produced from this seed could be screened for resistance or susceptibility to the fungus. If resistance holds up, seedlings could be used to reestablish butternut populations in areas where the disease has eliminated or killed most of the butternut. It may also be possible to cross butternut and black walnut in the hopes of transferring the black walnut resistance to butternut but, of course, the reverse might occur. Although developing genetic resistance is often a complex and long term undertaking, it may offer the greatest possibility for saving the butternut.

Black walnut is highly resistant to the Sirococcus fungus but history has shown that, through evolution, genetic changes can occur in the pathogen, the host, or both that can increase the susceptibility of a previously resistant host. Thus, it is important to have a good understanding of the butternut canker disease complex and the impact it might have on the closely related black walnut. It would not be a good practice to plant walnut among or near infected butternut trees.

ACKNOWLEDGMENTS

Many people have contributed to the information contained in this paper. I would like to thank Al Prey, Bill Pratt, Gary Holzbauer, and Adrian Hagen, Wisconsin Department of Natural Resources, for maintaining spore traps and weather stations throughout the study. Michael Ostry, Kenneth J. Kessler, Jr., and Barbara Weber, North Central Forest Experiment Station; and James Kuntz, University of Wisconsin, all provided help and timely advice. More than 35 other people helped in the dissection and data collection on diseased butternut trees. Appreciation is extended to all those who participated in this team effort to gain an initial understanding of butternut canker.

GROUP DISCUSSION

Green: Since you are looking at cankers which seem to be of fairly recent origin, have you looked at any other contiguous species? What's the original inoculum source?

Nicholls: I think what has happened has been very subtle. Butternut has been disappearing slowly over many years. North Carolina, South Carolina, there's hardly a butternut left. The oldtimers say we had butternut all over the eastern part of this country.

Shigo: What you have said and shown is a dead ringer for what Eldon Ross did with ash decline at Syracuse. The canker looks almost exactly the same. He was able to put Cytophoma on young ash seedlings and get infection. So seedling infection doesn't impress me too much because you can do that with a lot of fungi. Another point, you said, "The fungus kills because it girdles". You didn't show one slide where you had a girdle; does it really girdle? You also said that the fungus is walling off, and these are your words "it looks as if its trying to wall it off". Every canker you showed was indeed walled off. You were able to date the cankers from 1 to 12 years which means they have been walled off for many years. Another point, if you girdle a tree you don't get the kind of leaf crinkling that you showed.

Nicholls: I have seen coalescing cankers that do girdle trees. The ones you saw were on still living trees but if the older trees are dissected coalescing cankers are found. And wilting does occur just as it does with the greenhouse inoculations with Sirococcus.

Shigo: We talked about similarities of the butternut canker and the chestnut blight canker. A unique feature of chestnut blight as a canker disease is that it spreads circumferentially more than it does elliptically. Just about every butternut canker shown was an elliptical canker. They, for the most part, are not killer cankers. The only coalescing canker that comes close is found in the beech bark disease and even there only a small percentage of the trees are dying.

WOUND REACTIONS IN TWIGS OF BLACK WALNUT[1]

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ABSTRACT.--Since plants are not capable of replacing injured tissues, wounded areas are isolated from healthy portions of the plant by a number of anatomical and biochemical responses. Our anatomical studies of insect wounds of black walnut twigs have documented the injury responses and allowed us to make some generalizations about wound reactions in juvenile portions of the shoot system. The differences between the injury responses in twigs and trunks primarily reflect the obvious anatomical differences between juvenile and mature woody stems, i.e., wood comprises a much smaller proportion of the total stem volume in twigs. The compartmentalization of wounds in the wood of trunks and limbs has been well documented and is essentially the same in the wood of twigs. However, in twigs there is a considerable volume of additional tissues comprising the pith, the phloem, and the cortex, and in addition, parenchyma cells constitute a greater portion of newly formed (juvenile) wood. Depending on the location and severity of the wound, various combinations of wood compartmentalization, wound periderm formation, and cambial activity isolate the injured tissues and prevent pathogen invasion. The basic pattern of the response does not vary with the severity of the wound and is essentially similar for superficial treehopper oviposition wounds and for the severe wounds inflicted by a walnut shoot borer, Acrobasis demotella. These responses generally reflect the processes by which trees protect twig tissues following the natural abscission of leaves, stems, and fruits.

The purpose of this presentation is to review how the twigs of black walnut respond to injuries and to examine the effect of some common twig injuries on overall tree growth. The information in this presentation summarizes some of the results of an ongoing comprehensive study of wound reactions in black walnut being carried on at the School of Forestry, Fisheries and Wildlife, University of Missouri-Columbia, in cooperation with the USDA Forest Service. These studies include observations in mechanically, environmentally, and insect-inflicted wounds. Only the latter two categories concern the twigs since the first category was experimentally designed to study wood discoloration and compartmentalization in bole wood.

Although each insect wound was quite characteristic, the same types of anatomical and biochemical responses were observed in all instances. The response to the death of a terminal portion of a twig is quite similar whether caused by the feeding and tunneling of a shoot borer or a late frost. It is often said that with a very small bag of tricks nature achieves awe-inspiring variety. This report will review the little black bag of tricks with which a tree can respond to a wide variety of wounds. It will be seen that because of the effectiveness of the wound reactions, few twig wounds have a detrimental effect in themselves.

THE DIFFERENCES BETWEEN TWIGS AND TRUNKS

The differences between injury responses in twigs and trunks primarily reflect the obvious anatomical differences between juvenile and mature woody stems. Twigs have a considerable volume of non-woody tissues comprising the pith, phloem, and cortex. Gradually, through cambial activity, wood accumulates until it volumentrically comprises the vast majority of trunks. To the outside, the cambium is annually producing phloem, however, rather than continually accumulating, the older portions of the phloem are cut off by the formation of cork (periderm) and eventually shed. The functional phloem, old phloem, and corky tissues together comprise the bark. In addition to phloem, young twigs initially have a cortex between the vascular cylinder and the epidermis. The first periderm is formed in the outer cells of the cortex beneath the epidermis.

[1] Not presented at Workshop.

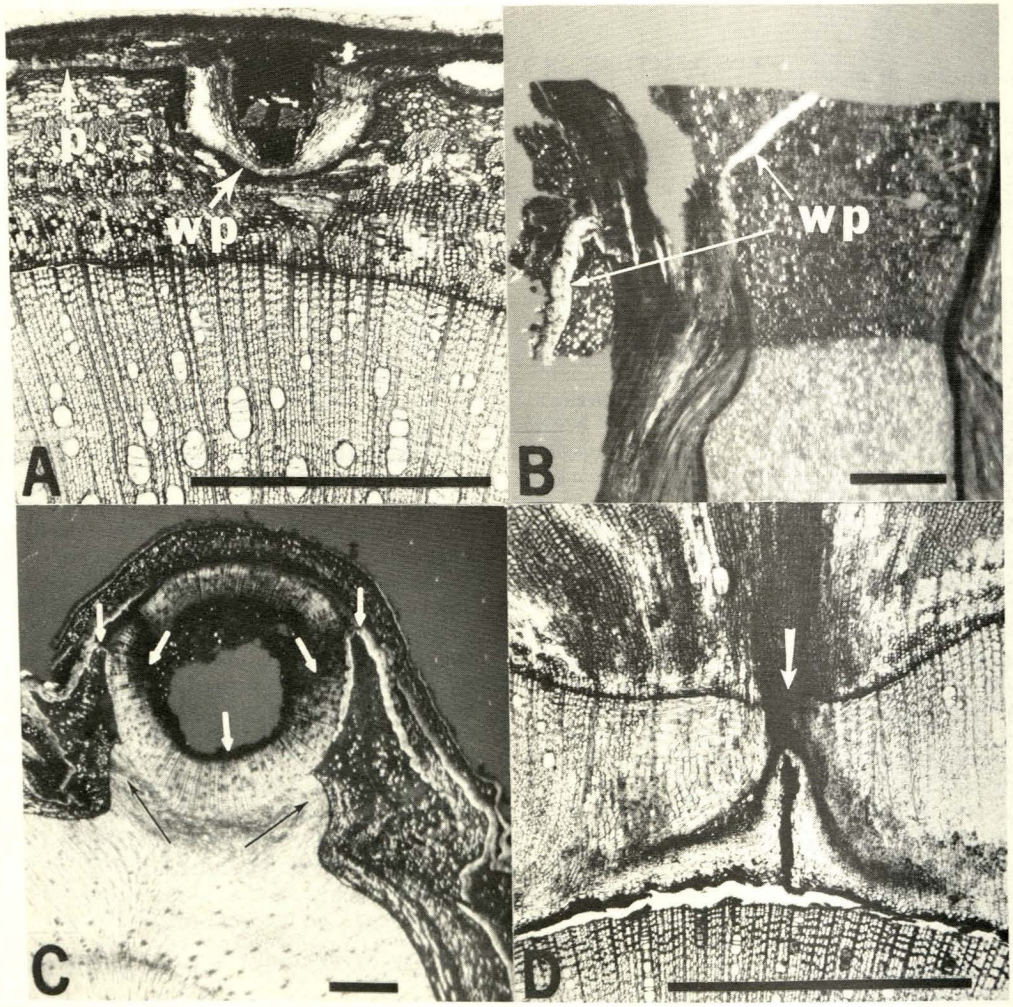

Figure 1.--Microscopic views of wound responses.

A. *Wound periderm (WP) which is continuous with the regular periderm (P) has isolated superficial injury to the cortex and old phloem of a two-year-old twig. There was no cambial response to this wound. BAR equals 1 mm.*

B. *Longitudinally sectioned twig showing a portion of a diagonal plate of wound periderm (WP) viewed with polarized light. The characteristic birefringence is caused by the layered deposits of suberin and waxy substances in the periderm cell walls. Terminal portion of the twig (top, no shown) died following shoot borer injury. Wound periderm crosses, from left to right, the cortex and phloem, then skipping the xylem crosses the pith. Slight birefringence in intervening xylem indicates some deposition of suberin in ray parenchyma. Boundary between first-year pith and one-year-old pith (bottom) is evident because of the birefrigent secondary walls of the older cells. BAR equals 1 mm.*

C. *Cross section at the base of a dead twig showing isolation by a combination of wound periderm and wood compartmentalization (white arrows). Dead tissue is at the top of this section. Lower left third of the frame is a developing lateral twig, compare with Fig. 2, D. Cambial activity would have eventually enclosed twig stub (black arrows). BAR equals 1 mm.*

D. *Cross section of a two-year-old twig showing callus formation and cambial activity following treehopper ovipositor injury. Split tissue at bottom indicates the position of cambium at the time of wounding, late summer. Cambium reorganized toward central callus tissue and produced abnormal derivatives. Cambium, dark line of cells above center, hasn't reformed across small central portion of callus (arrow). BAR equals 1 mm.*

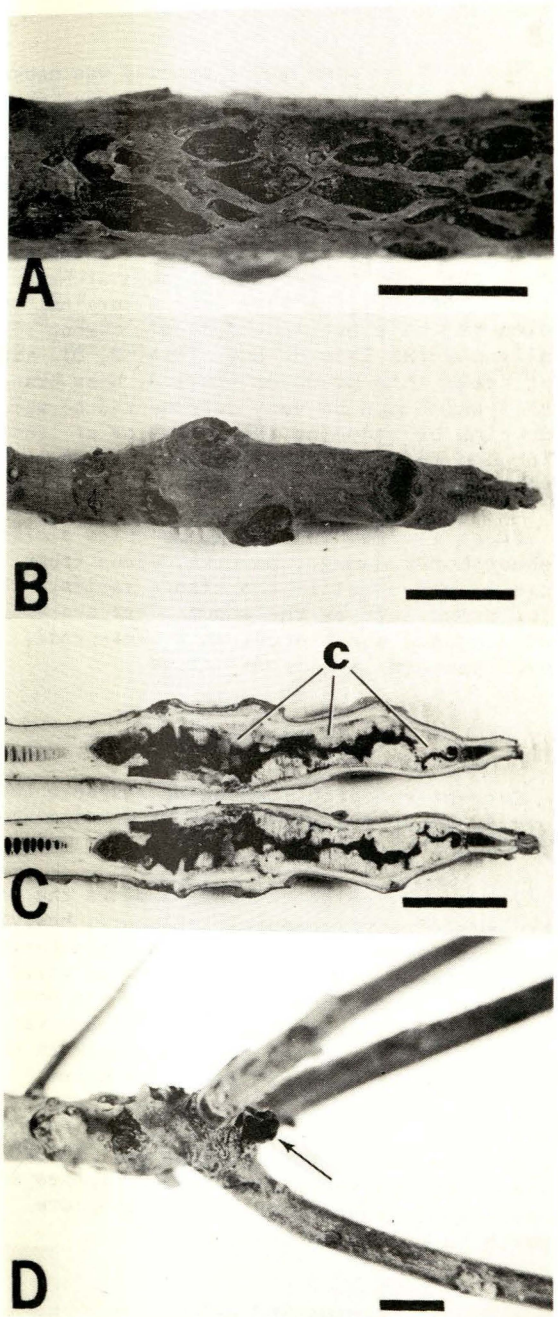

Figure 2.--Macroscopic views of wounded black walnut twigs.

A. One-year-old treehopper ovipositor scars on two-year-old twig. Internally the wounds have healed and would vary from something similar to Fig. 1, A to Fig. 1, D. BAR equals 1 cm.

B. Stunted, swollen one-year-old twig following attack by unidentified insect. BAR equals 1 cm.

C. Same twig as in B, split longitudinally to show development of callus (C) which causes the swelling. Black area consists of dead cells and insect detritus. Normal chambered pith is at left. BAR equals 1 cm.

D. Dead terminal twig stub (arrow) one year after shoot borer attack. Note the whorl of developing lateral twigs. BAR equals 1 cm.

WOUND RESPONSES

Since plants are not capable of replacing injured tissues, wounded areas are isolated from healthy portions of the plant by a number of anatomical and biochemical responses. The cortex and pith are largely composed of parenchyma cells. The phloem and young wood also contain a considerable amount of both axially and radially oriented parenchyma cells. It is these cells which are capable of a trauma-induced dedifferentiation giving rise to callus tissue, cork or vessel tyloses. The parenchyma cells plus cambial activity are therefore responsible for isolating injuries and restoring normal stem structure and function. Injured tissues outside the cambium are isolated and eventually lost with exfoliating cork, along with the old cortex and phloem. However, inside the cambium injured tissues are isolated but never lost.

Deposition of protective substances and cork formation.--The deposition of suberin and other substances in cells surrounding a wound is a biochemical reaction that appears to protect underlying tissues. This reaction is more noticeable in the cortex, phloem, and pith than in the wood, probably because of the diffuse arrangement of live cells in young wood. This is a plant's most immediate response to injury.

In the cortex, phloem, and pith a periderm is formed underlying the zone of deposition. It is probable that the deposition of suberin and/or other substances (phenolic) must preceed periderm formation and provides the proper cellular climate for the dedifferentiation of parenchyma cells leading to periderm formation (Mullick, 1977). The wound periderm is usually continuous externally with the normal periderm, and, if the wound is deep enough, internally with the cambium (Fig. 1).

Cambial activity and callus formation.--The cambium reacts to a nearby wound by producing abnormal derivatives. The rate of cell divisions is usually increased, especially if the cell division rate has naturally slowed down or ceased toward the end of a growing season. If the cambium is directly injured there is a proliferation by cells near the wound producing a callus composed of parenchyma cells (Fig. 1, D). Not only does the callus close the wound, but a new vascular cambium and cork cambium are established in this tissue (Fig. 1, D). It is also possible for pith cells remaining after insect feeding to form a callus which refills the hollow pith (Fig. 2, C). In some cases the proliferation of callus can cause the twigs to swell and gives the appearance of a gall-like formation (Fig. 2, B-C).

Wood and compartmentalization.--The compartmental nature of wood structure and wound reactions has been well documented (Shigo, 1975, 1976; Shigo and Marx, 1977) and is essentially the same in the juvenile wood of twigs. Juvenile wood has the same compartmental structure, although, in first-year wood the inner wall 2 (tangential wall of latewood in mature wood) is formed by pith parenchyma rather than the terminal parenchyma and latewood fiber of the previous year's growth. Compartmentalization in juvenile wood is very good because of a higher proportion of parenchyma cells than in mature wood, and the high proportion of these cells that are alive and capable of reacting to injury. As each year's wood becomes a year older, the number of live parenchyma cells decreases until the wood is nearly completely dead and incapable of a positive significant response to injury.

DETRIMENTAL EFFECTS OF INSECT WOUNDS

In general the wound responses of black walnut twigs are very good and the detrimental effect to the tree are minimal. A treehopper, Enchenopa binotata produced ovipositor wounds that were essentially superficial, completely healing in a single season, although an external scar persisted (Armstrong, Kearby, and McGinnes, unpublished report) (Fig. 2, A). These wounds leave a small callus inclusion in the wood, but don't seem to be a point of entry for pathogenic organisms.

An as yet unidentified insect produced somewhat more serious wounds, tunneling and feeding in the pith of elongating black walnut twigs. The resulting proliferation of callus tissue caused a gall-like bulge at the base of a stunted twig (Fig. 2, B-C). On a mature tree the twig deformities would be negligable, while a young tree's form could be adversely affected.

The most serious wound studied was caused by the feeding and tunneling of a walnut shoot borer, Acrobasis demotella (Kearby, 1978). Expanding twigs attacked by the larvae of A. demotella usually died. An effective wound response isolated the dead terminal and prevents entry of pathogenic organisms. Continued cambial activity will eventually enclose the dead twig stub in the same manner that branch stubs are healed. However, the loss of the terminal bud results in the elongation and development of usually several lateral buds (Fig. 2, D). In young trees this produces whorled, busy branching pattern which can be very detrimental to wood production by reducing the length or at least prolonging the time necessary to grow an adequate length of clear bole.

Frost damage, if severe, is quite similar to shoot borer damage, however, since frost damage is not specific the effect varies. The hollow twigs left by the shoot borer are easily identified and don't occur in a widespread, general pattern like frost damage.

SUMMARY

Current research finding of response to injury in young twigs of black walnut indicates that:

1. Mechanism of response appears the same regardless of environmental influence; however, each causative factor has its own characteristic pattern. Treehopper damage is minimal while shoot borer damage and frost damage are more severe. Frost damage produces a greater variety (range) of effects which seem plausible in view of wide range of "severe" frost exposures possible.

2. The anatomical response pattern can be well documented--the biochemical responses are not completely understood to date and more research is needed in this area.

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PATTERNS OF DISCOLORED AND DECAYED WOOD IN BLACK WALNUT

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ABSTRACT.--After wounding, trees compartmentalize injured and infected tissues. This process appears to be under genetic control. How effectively a tree compartmentalizes injured and infected tissues is a major factor that determines the limits or configuration of the defect column. The microorganisms involved in the successional patterns are major factors that determine the rate of the discoloration and decay processes. Discolored and decayed wood in black walnut can be detected by the Shigometer. New information about compartmentalization, succession, and the Shigometer gives new opportunities to regulate and to detect discolored and decayed wood in black walnut.

Black walnut takes us from the forest to the single tree. The extremely high prices paid for selected single trees during the last few years have caused increased concern for internal defects caused by discolored and decayed wood. Buyers cannot use broad estimates of defect for great numbers of trees in a forest when they need to determine the exact internal condition of selected single trees. This new demand for increased accuracy must be met with new information from research. The same situation obtains for the growers. They need better information from research on how to grow higher quality trees with fewer defects.

For the last 19 years at the Northeastern Forest Experiment Station, research on discoloration and decay in living trees has anticipated these demands, and more information is now available to help the growers and the buyers.

WHAT'S NEW?

The person who wants to grow high quality, high priced, defect-free black walnut trees has two very important questions for the research pathologists who are studying defects: What have you done that will help me now? What are you doing that will continue to help me as new problems arise?

In answer to the first question, we now have an expanded concept of tree decay to serve as a basis for decision making; and, to move this concept out to the person in the field, we have a new model system called CODIT that will help explain the development and configuration of defects in trees. We also have new electrical equipment that will detect internal defects in trees.

This information also helps to clarify misconceptions about the tree decay process. In so doing, it helps to refute some myths such as frost causes frost cracks, wind causes ring shakes, and that decay progresses indiscriminately through heartwood.

In answer to the second question, we now have new information that suggests that the wound response is under genetic control. This means that we may be able to start selecting for decay-resistant trees.

ROLE OF THE RESEARCHER

The researcher has the responsibility to package this new information together with sound older information in a form that will reach the people who need it. The people who ask for the information have the responsibility to use it.

Too often researchers are criticized for not providing user groups with the information they need. This may be so in some areas, but it is not so with the subject of internal defects of trees--the information is available. It has been published and packaged in many different forms to reach many user groups, so the intent here is to give only brief summaries of available information. Please contact the author for additional details.

DEFECTS AND VALUES

Discolored and decayed wood are major defects that affect the value of the black walnut tree. A tree that looks fine from the outside may have many internal defects. The converse may also be true. How is a buyer to know what the actual internal condition is? Research has provided a new device to help; it is called the Shigometer. When used correctly, this electrical pulse resistance meter provides information that can be interpreted to determine the internal condition of a tree. The meter can also be used to determine relative growth rates in trees, and this information can be used to help select trees for thinning.

The grower wants to know how to grow trees with fewer defects. Before this can be done, the grower must understand how defects start and how they continue to develop.

The classical concept of tree decay lacks information on many essential phases of the decay process. The new concept includes compartmentalization--the response of the tree to wounding; and succession--the presence of many microorganisms in the processes that result in discolored and decayed wood.

A simple model system called CODIT--an acronym for Compartmentalization Of Decay In Trees--has been developed. The system explains how a tree is compartmented and how it reacts after wounding by compartmentalizing the injured and infected wood. The system is based on four numbers: 1, 2, 3, and 4, which denote "walls" in the model. Each growth ring is divided into compartments. After wounding, the "walls" begin to confine the injured and infected wood. Walls 1 are the horizontal top and bottom of the compartments. Walls 2 are the tangential sides. Walls 3 are the radial sides. Wall 4 is the barrier zone formed by the cambium after wounding. The CODIT model can serve as a basis for understanding the development of defects in a wide variety of trees--deciduous hardwoods, and conifers of the temperate and tropical forests.

When a person uses the CODIT model along with external indicators and the Shigometer, he can determine the internal condition of the tree with great accuracy. And greater accuracy is required now because of the increasing emphasis on the single tree. This is how better concepts, better methods, better tools, and better recommendations can be used to help growers and buyers.

DISCOLORED WOOD, DECAYED WOOD

We know that wounds start the processes that lead to discolored and decayed wood (Fig. 1). In discolored wood, the cell contents and

Figure 1.--Logging injury at base of black walnut tree. Mechanical wounds start the processes that lead to discolored and decayed wood. Wounds must be prevented if high quality trees are desired.

walls have been altered in such a way that the color is different from nonaltered, healthy wood. There is no loss in strength. In decayed wood, cell walls have been digested. There is loss in strength.

A wide variety of microorganisms are involved in the processes that result in discolored and decayed wood: decay-causing fungi, non decay-causing fungi, and bacteria. They infect wounds in succession where bacteria and non decay-causing fungi may be the first microorganisms to interact with the tree; while in other cases, the decay-causing fungi may be the first. Regardless of the exact sequence, it is not the heartwood-rotting fungi alone, but many microorganisms that are involved in the infection processes.

A wound exposes injured wood. The tree reacts to the injury by forming a chemical protective barrier beneath and around the injured wood. Slight alterations in the color of the wood could result from these processes. When some microorganisms are able to surmount the protective barriers set up by the tree, the tree responds further to this infection and the altered color of the wood may be further intensified. These

processes occur in sapwood and heartwood. It is often difficult to recognize slight changes in the color of the dark heartwood of black walnut, but discolored heartwood is common.

The columns of discolored wood in the heartwood often result in a banding pattern. The bands or columns of discolored wood are associated with wounds. The most common wound is the branch stub. All trees have branches, and all trees will have some dead branches. The branching habit and the formation of stubs are major factors that affect the pattern of discolored wood in the heartwood. This means that black walnut trees with large, dying branches will have many columns of dark discolored wood in the heartwood.

TREES REACT TO WOUNDS

The wounded tree reacts not only in a chemical way, but also in an anatomical way. A tree is a highly compartmented plant. After wounding, the tree responds by confining, walling-off, or compartmentalizing the injured and infected tissues in the sapwood and heartwood.

After wounding, the living cambium begins to form a new tissue--the barrier zone. It is an anatomical and a chemical zone that separates the tissues present at the time of wounding from those that will continue to form. When wounds are inflicted during the dormant period, the cambium begins to form the barrier zone when growth is resumed. The extent of the barrier zone is determined by many factors: the size, position, and severity of the wound, and the genetic capacity of the tree to respond to the injury. The barrier zone is a highly protective tissue for the tree, but it serves as a plane of weakness when mechanical stresses occur.

BARRIER ZONE AND DEFECTS

The barrier zone is the primary site for ring shakes, which in turn are the beginning of many radial cracks commonly called "frost cracks". Most ring shakes and frost cracks are associated with wounds. Most frost cracks start from the inside and develop outward. The frost or cold serves to stress the wood, and it cracks along the internal plane of weakness that was set up by a wound. It must be remembered that branch stubs are wounds, and every tree will have some wounds of this type. Not all wounds lead to ring shakes and frost cracks, but all ring shakes and frost cracks observed by the author have been associated with wounds.

PRUNING WOUNDS

Wounds caused by faulty pruning can serve as starting points for many internal defects in black walnut--bands of dark discolored wood, ring shakes, and even radial seams. Pruning is definitely not a "cure all" for black walnut (Fig. 2). If pruning is to be done, it must be started early in the life of the tree and continued as needed until the tree reaches early maturity. Great care must be taken if trees over 8 inches in diameter are to be pruned for the first time. When this is done, a person must understand the "trade offs". When dead and dying branches are pruned, the callus branch collar must not be cut flush with the stem. This will cause a severe wound that could lead to large columns of discolored wood, and possible ring shakes (Fig. 3). When callus branch collars are present, the branch should be cut in such a way that the collar is not injured. The trade off is a shorter length but higher quality of clear stem. Another reason why we must take another look at pruning is because of the chain saw. The powerful, lightweight chain saw makes it too easy to make long, flush cuts through callus branch collars.

Figure 2.--Pruning is not a "cure all". Dieback around some pruning cuts greatly enlarge the wound.

Figure 3.--The dark band of discolored heartwood formed after the branch was pruned. The cambium formed a barrier zone (arrows) that separated wood present at the time of wounding from wood that formed subsequently. The barrier zone is sometimes the site of ring shakes.

As a result of poor pruning techniques and the increased number of injuries to the boles of trees caused by the use of more heavy equipment around trees, the problem of discolored wood will become more urgent. It is relatively easy to recognize decayed wood, but it is often very difficult to assess the amount of discolored wood in a tree or log until it is made into veneer. Then it is too late!

GENETICS OF THE WOUND RESPONSE

Wound one black walnut tree, and it compartmentalizes the discolored and decayed wood to a very small volume (Fig. 4). Wound another black walnut tree in the same way at the same time, and the volume of discolored and decayed wood may be many times greater than that of the other tree. Why? It appears that the compartmentalizing capacity of individual trees is under genetic control. This does not mean that decay will not develop in a tree, but it may be confined to a very small volume in one tree and extend to a very large volume in another tree of the same species. From experiments on other tree species, it appears that the compartmentalizing capacity is not associated with growth rate. A simple wounding technique has been developed to determine the relative compartmentalizing capacity of a tree. The tree is wounded with a drill bit several times. After a set time, the condition of the wood above the wound is determined with the Shigometer. Trees that have very small columns can be easily identified, and then used as parents.

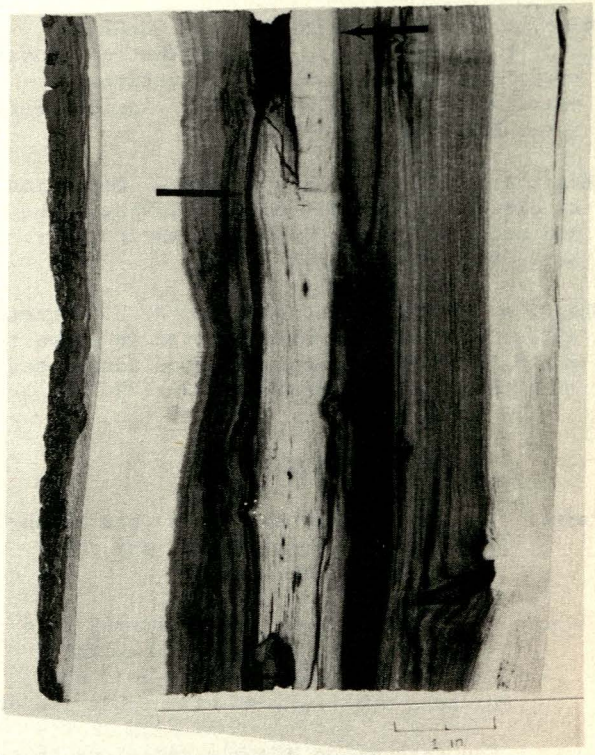

Figure 4.--Compartmentalization of decay in heartwood (arrows). The decay will not spread out to the surrounding heartwood.

WHAT NOW?

We must move available information into use. Defects don't just happen--we must reduce mechanical wounds and we must reassess pruning techniques. Also, we must use new methods to detect defects, and begin to select trees that have a strong compartmentalizing capacity.

ACKNOWLEDGMENT

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GROUP DISCUSSION

Payne: You say that trunk cracks once established stay established? Why can't they callus over?

Shigo: They will in some trees after 2 to 4 years. But it is almost inevitable that at some later time a cold spell or some other stress will cause reopening.

Kuntz: You talk about disease reactions in terms of barriers to decay columns and the possibility of selecting trees that have this capacity to compartmentalize. Do you see any evidence that this type of compartmentalization is effective against canker and vascular wilt organisms?

Shigo: I don't have the answer to this. But we do know this: you drill holes in trees and you will find that certain trees will have much more dieback around the holes. In some ways that might be likened to a canker. This might be related to why cankers spread more on some trees than others.

Kuntz: Is compartmentalization more common in white oaks than red oaks?

Shigo: I will say not more common. I would say it was more effective in the white oaks than in the red oaks.

Kuntz: When we were looking at grafts on oak root systems we often noticed examples where decay came in the lateral roots and when it encountered a graft; that's as far as it went. Why didn't it continue on?

Shigo: Because you have a new tree. In a sense you have a new group of compartments at a graft union.

Nicholls: Could you clarify callus tissue and barrier tissue?

Shigo: Callus tissue is the undifferentiated tissue found after a tree is wounded. It can be primarily around a wound where it's going to be a next year's growth ring. Because the cells are on the outside and do not have equal pressures on their sides they continue to grow without definite form. The barrier zone is formed far above and below the wound site and will not be associated with an increase in the amount of wood produced. The barrier zone is both a chemical and anatomical tissue. You cannot see the barrier zone. We know it more as a model. There are at least six laboratories who are trying to answer your question "what is the barrier zone?". We know that it is a phenol rich zone--it's an area where changes of lignins occur, it's an area with all kinds of metabolic shunts.

Kuntz: Are tree injections practical?

Shigo: We must use the present injection methods very carefully. For example with Dutch elm disease after injecting each year for four or five years you run out of space for injection holes. You say put them at the base of the tree--you run out of the base of the tree after five years, too.

Nair: Why does this bother you when you say every ring is a new tree?

Shigo: The elm tree has a 15-25 ring of sapwood. When you reduce that sapwood down to one ring, and that ring is not continuous because of the cankering around many of the holes, you may have a growth ring that is only 10% alive. Then when you need to inject the theraputic material into the tree you've got one-tenth of a growth ring into which to move the material.

Nair: As long as you don't girdle it, it will move.

Shigo: Yes, it will move, but you have to use all kinds of pressure. Remember you can't move materials through dead wood, and discolored wood in this place is dead wood.

PECAN PEST RESEARCH

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ABSTRACT.--The rapid growth of the pecan industry has brought about new problems in insect control. With the trend away from native stands where every tree is genetically different toward groves of uniform cultivars, the damage caused by insects is more severe. The total yield as well as nut size and quality can be reduced by 20 or more species of insects and mites. These pests also reduce the vitality of pecan trees by damaging the leaves, buds, fruit, twigs, branches, bark, and even roots. This feeding damage can injure the tree so that developing pecans cannot mature, or it can damage the tree to such an extent that pecan production is drastically reduced the following year. Control is often difficult because of the complexity and size of the arthropod fauna as well as the large tree size. The pests multiply rapidly because large acreages of pecan groves provide an abundance of the food they prefer. Species that were not common in the past have moved from hickories and other host plants.

Man's monoculture of plants has made production economically and physically sound but at the expense of tremendous modifications in the natural environment. Concentrated food production has made knowledge about the technology of pest control exceedingly important. With the current trend away from native stands where every tree is genetically different toward groves of uniform cultivars, the damage caused by insects is more severe. The pests multiply rapidly because large acreages of trees provide an abundance of the food they prefer. Species that were not common in the past have moved to pecan trees from hickories and from other host plants. Where row after row of single nut crop is produced, it is no wonder that new pests find happy hunting grounds. Under these conditions, the balance of natural control is upset, and pest populations build up rapidly if left unchecked.

There are at least 180 species of insects and mites that feed upon the wood, foliage, shoots, bark, or nuts of pecan and hickory. Most of the important insects in the Pecan Belt[1] are also serious pests on northern pecans and other hickory species; occasionally some species attack walnut and other fruit trees. More than 20 species of insects affect pecan production by feeding on the fruit or by injuring the tree so severely that developing pecans may not mature; or they can damage the tree to such an extent that pecan production is drastically reduced the following year. These pest species usually require some method of control to protect the crop. We present here a brief discussion of biology, damage, distribution, and control for approximately 20 major pecan pests.

OBSCURE SCALE

The obscure scale, Melanaspis obscura (Comstock), is found in most areas of the Pecan Belt, and it is a sufficiently serious pest of pecans in Texas, Louisiana, Arkansas, and Mississippi, so that chemical control is often necessary. Its body, about one-eighth inch long, is covered with a circular dark-gray scalelike substance. Its body coloration is similar to that of the tree bark, which makes detection difficult. It attacks both branches and tree trunk. The bark of heavily infested branches appears roughened or scaly.

[1] The pecan is grown principally across the southern United States in a belt that includes Alabama, Arizona, Arkansas, Florida, Georgia, Louisiana, Mississippi, New Mexico, Oklahoma, South Carolina, and Texas.

Since scale sucks the sap from plant tissues, it can gradually kill branches less than 3 inches in diameter. Larger branches are seldom killed, though they may be so weakened that they will not produce a normal crop. Slow, progressive destruction of infested branches reduces the number of fruiting shoots and weakens the tree which makes it subject to attack by wood boring insects.

Scale produces only one generation each year. The young, called crawlers, are present from about the middle of May until early August. Soon after they hatch, the crawlers settle on the bark, insert their beaks, and begin to form their waxy scale coverings. They gradually increase in size and, except for the adult males, do not move around. Female scales overwinter under their scaly covering on bark.

Control: Chemical control of scales is often necessary. A single oil spray in the early spring while the tree is still dormant will keep this pest under control.

PHYLLOXERA

Two species, Phylloxera notabilis Pergande and P. devastatrix Pergande, are found in almost all sections of the Pecan Belt, from Georgia in the east through Texas in the west. Both species overwinter in the egg stage. When they hatch in the spring, these small soft-bodied sucking insects feed on new plant growth, and cause tumorlike swellings or galls, one-tenth to 1 inch in diameter, to appear on leaves, leafstalks, succulent shoots, and nuts. The pecan phylloxera, P. devastatrix, is the most damaging; this insect causes malformed, weakened shoots that finally die. Severe infestations can destroy entire trees. Serious damage has been reported in Arkansas, Louisiana, Mississippi, Oklahoma, and Texas.

Control: Spray trees thoroughly during the delayed dormant period or spray before the buds of earliest varieties show 1 inch of new growth.

PECAN BUD MOTH

The larvae of the pecan bud moth, Gretchena bolliana (Slingerland), often cause serious damage to pecan nursery stock by feeding on terminal buds and foliage. The damage causes excessive branching and stunted growth in young pecan trees and sometimes loss of the grafted bud. The larvae occasionally defoliate large pecan trees, feed on young nuts in spring, and infest the shucks in fall. The insect overwinters as an adult. The moths begin laying eggs on the twigs near buds when the buds open in spring. When foliage appears, they lay more eggs on the upper surfaces of the leaves. The mature larvae, about one-half inch long, are creamy to dirty white at first, becoming yellowish green with dark-brown heads and necks. After they feed for 25 days, they pupate in rolled-up leaves or infested buds, but occasionally under bark scales. There are probably five or six generations each year.

Control: Vigorous young nursery trees kept healthy by proper water, cultivation, and fertilization usually recover from bud moth attack better than weaker ones. Control is usually necessary in nurseries but seldom necessary in bearing groves.

PECAN NUT CASEBEARER

The pecan nut casebearer, the larva of the moth Acrobasis nuxvorella Neunzig, causes damage throughout the Pecan Belt. Only Arizona and California have escaped this pecan pest. Losses vary with the size of the crop. A light-to-moderate infestation in a heavy set of nuts may merely provide desirable thinning, but in a light crop most nuts may be destroyed.

Partly grown casebearers pass the winter in small, tightly woven cocoons called hibernacula that are usually found where a bud joins the stem and under bark on the limbs and trunk. The casebearers become active in spring about the time the buds begin to open. They feed for a short time on buds and then bore into the young tender shoots, where they pupate. The moths usually emerge in May and are most numerous about the time of nut set. They lay greenish-white oval eggs on the blossom end of the nut, usually near the base of the calyx lobes. Commonly, only one or two eggs are laid in a cluster of nuts.

The first-generation larvae cause most of the damage in May and June. These newly hatched casebearers descend from the nut clusters to feed on the buds just below. A few days later, they return to the clusters and attack the newly set nuts, normally entering them at the stem end. Infested nuts are held together by silken threads and are easily recognized by the conspicuous frass cast out by the larvae. In the course of development, a single casebearer of this generation may destroy all the nuts in a cluster. Larvae mature and pupate in one of the last nuts they attack.

Second-generation moths appear in late June and early July. Larvae of this generation also attack the nuts, but the loss is less because the nuts are larger, and the individual case-bearer requires fewer nuts for its development.

Control: Growers should spray with the recommended pesticides if over 3 percent of the previous year's shoots are infested with over-wintering larvae or if there is a history of serious infestation.

YELLOW APHIDS

The blackmargined aphid, Monellia caryella (Fitch), is found throughout the United States on pecan and certain other Carya species. It feeds mostly on the undersides of the leaves and prefers the primary and secondary veins. The summer form adults are parthenogenetic, and they produce live birth. They are easily recognized, as the wings are held flat over the body when the aphid is at rest and the outer edges of the forewings are colored black. The body is pale yellow and also edged with black. When these aphids are present in large numbers, the honeydew they excrete causes the foliage to become sticky and appear glossy. In humid climates, sooty mold subsequently grows on the honeydew, which gives the foliage a black sooty appearance. This black coating reduces the capacity of the leaves to manufacture starch, which reduces the vigor of the tree. Heavy feeding in late summer causes damage to the veins and sometimes leaflet shed. In the South there may be as many as 30 generations per year. This species is usually most abundant after midsummer.

A second yellow species, Monelliopsis nigropunctata (Granovsky) is found on the foliage of pecan and the other species of Carya in North America. It feeds almost entirely on the undersides of the leaflets on the tertiary veins at the point where these veins intersect larger veins. Feeding sites are therefore scattered across the leaflet blade. The summer form adults are parthenogenetic and give live birth. They are distinguished from the black-margined aphid by the way they hold their wings when at rest. Also, the wings lack black margins, and only insignificant amounts of black occur on the body. The body is brighter yellow than that of the black margined aphid. This aphid produces about 60% of the honeydew that the blackmargined aphid produces, but the sooty mold effects are similar. Heavy feeding in the late summer causes damage to the veins at the point of feeding and sometimes leaflet shed. There may be as many as 32 generations annually. The aphid is usually most abundant in the spring but large populations also occur in late summer.

Control: Large aphid populations require chemical control, but indiscriminate use of pesticides kill predaceous insects, parasites and entomogenous fungi that help control aphids. In early season, controls should be applied when aphid numbers exceed an average of 20 aphids per compound leaf. In late season, this threshhold for control should be reduced to an average of 10 aphids per leaf.

BLACK PECAN APHID

The black pecan aphid, Tinocallis caryaefoliae (Davis), is considered more destructive than other aphid species because its feeding may cause defoliation in a short time. The first signs of feeding are the appearance of pale to bright-yellow rectangular areas on the leaflets; the color depends on the season and cultivar attacked. These yellow areas (up to one-fourth inch in diameter) eventually turn brown, and the entire leaf may drop prematurely. Black aphids feed on both sides of the leaflet and prefer the shaded, inner portion of the tree, but as injured leaflets drop, the aphids migrate toward the outside of the tree. Premature dropping of many leaves reduces the supply of food for the tree, prevents proper nut filling, and reduces the next year's bloom. Up to 26 successive generations occur through the summer, and each mature aphid produces about 40 young.

Control: Under certain conditions even small populations require chemical control because black pecan aphids can completely defoliate an orchard within 30 days. Controls should be applied when an average of one black aphid per compound leaf is found or their damage is seen frequently.

SPITTLEBUGS

The pecan spittlebug, Clastoptera achatina Germar, and the alder spittlebug, C. obtusa (Say), are common on pecan trees along the gulf coast, up the Atlantic coast from Florida to Massachusetts, and westward to Texas. They are prevalent in parts of Kentucky and Illinois.

Groups of young bugs (spittlebug nymphs) clustered together produce masses of white, foamy froth about the buds, tender shoots, and nut clusters. They are commonly found in spring soon after the nuts have set and then appear again in midsummer. They suck the juices from tender growth, and heavy infestations kill the terminal shoots, resulting in a reduced crop.

Control: Large populations of spittlebugs require chemical control. Controls should be applied if 5 percent or more of the terminals have spittle masses. Light infestations generally do not cause enough damage to make control necessary.

LEAFMINERS

Leafminers, which are the larvae of certain moths, are among the smallest plant-feeding insects. They find both food and shelter in the thin space between the upper and lower surfaces of a single pecan leaflet. Each larva consumes only a small quantity of leaf as it develops, but the damage caused by excessive numbers and successive generations cannot be disregarded. Heavy infestations of these insects may defoliate pecan trees during late summer and fall. Although leafminers are widespread and have been observed in both the eastern and western United States on various species of hickory, walnut, and butternut, economically damaging infestations are not common.

A serpentine leafminer, Nepticula juglandifoliella Clemens is found wherever pecans are grown. The larvae confine their feeding to the chlorophyll containing cells just beneath the upper surface of the leaf, making a linear, or serpentine, mine about 2 inches long and one-twelfth inch wide, whitish to light tan in color, with a black line of frass running through the center.

Two other leafminers, Cameraria caryaefoliella (Clemens), which forms an upper-surface blotch mine, and Phyllonorycter caryaealbella (Chambers), which forms a lower-surface blotch mine, are also found on pecan. When the blotch mines are fresh, the separated leaf cuticle is a noticeable whitish color, commonly referred to as a frog eye.

Control: Light infestations of leafminers do not cause sufficient damage to warrant control. Apply controls when an average of 5 mines per leaf are observed. Insecticides used for aphids or hickory shuckworms will usually control these pests; however, excessive use of certain insecticides often cause leafminer outbreaks.

HICKORY SHUCKWORM

The hickory shuckworm, the larva of the moth Laspeyresia caryana (Fitch) is one of the most destructive insects that infest the pecan. It is generally distributed throughout the Pecan Belt from Georgia and South Carolina in the east through Texas in the west. Shuckworms also feed on hickory nuts and cause injury similar to that done to pecan. The shuckworm is primarily a nut infesting pest, but it is commonly found feeding in phylloxera galls on pecan in early spring.

Hickory shuckworms attack the nuts from about the first of June until harvest. From the time of first appearance until shell hardening late in August, these insects can continually destroy the interior of the nuts. Immature nuts infested early in the season fall to the ground. It is usually difficult to see the entry holes made by shuckworms except under magnification. Their presence, however, may often be detected in newly dropped nuts by a powdery white stain around the entry point. Much of the crop may be lost to shuckworms, especially when there is a light nut set.

After shell hardening, shuckworms tunnel in the green shucks and prevent the kernels from developing properly. Infested nuts may be poorly filled and may mature later than healthy nuts. Injured portions of the shucks stick to the nuts and interfere with processing, and the shells are often badly stained. Shuckworms pass the winter as full grown larvae in the shucks and emerge as moths the following spring.

Control: Growers with few trees and those not equipped to spray may reduce infestation by gathering and destroying pecan shucks at harvest. Plowing the shucks under in early spring may aid in control. The drops (small nuts) should be gathered and burned during midsummer. Proper insecticide application can reduce shuckworm populations to an insignificant level. Or 22-watt circline blacklight traps (2/acre) can be used to reduce shuckworm moth populations.

CURCULIOS

Conotrachelus hicoriae (Schoof), the so-called nut curculio, attacks several varieties of immature pecan nuts from late June through early August in some parts of Louisiana, Georgia, Arkansas, and Mississippi. The adult curculio deposits a single egg in the shuck of each nut during late June or early July. The puncture and the larval feeding within the shucks cause a bleeding of brown sap on the shuck and premature nut drop. Like the shuckworms, the creamy-white larvae continue to feed in the dropped nuts for about 2 weeks before leaving the nut. They form a pupal cell in the upper 2 to 4 inches of the soil. The adults emerge from August to October. The insect produces but one generation a year.

Control: When trees have a good nut crop, C. hicoriae damage may go unnoticed or be attributed to hickory shuckworms. Chemical spray may be necessary when jarring the tree indicates the presence of many adults.

STINK BUGS AND OTHER PLANT BUGS

The southern green stink bug, Nezara viridula (L.), the leaffooted bug, Leptoglossus phyllopus (L.), and similar sucking insects cause black pit and kernel spot of pecan nuts. Darkened insides of immature nuts, known as black pit, often indicate stink bug feeding before shell hardening. This feeding causes premature dropping. Brown or black stains sometimes develop on the shuck at the puncture site, and soon after the nuts drop, these spread over the entire shuck surface. Stink bug punctures occurring after shell hardening do not cause nut drop. However, black to brown spots from one-sixteenth to three-sixteenths inch in diameter that form a pithy, porous area known as kernel spot are seen after shelling. The spots produce a localized bitter taste that does not extend to the rest of the kernel. The severity of damage varies with the number of plant bugs in a grove. The abundance of bugs depends on the presence of the native plants or cover crops on which they breed or adjacent agronomic crops.

Control: The avoidance of summer legumes such as cowpeas, soybeans, and peanuts and of garden crops such as okra, beans, pumpkins, squash, and tomatoes near pecan groves will help control plant bugs.

PECAN WEEVIL

Pecan weevils, Curculio caryae (Horn), cause two kinds of nut damage depending on the stage of nut development at the time of attack.

The first damage is caused by adult weevils feeding on kernels in the water stage, before shell hardening. This feeding generally results in a drop of all punctured nuts, but the infestation may pass unnoticed because other insects and factors can also cause a premature nut drop. Weevil-punctured nuts can be identified by a tobacco juicelike stain around the feeding site. Dark patches develop on the nut surface, and in a few days the nuts drop from the trees.

The second kind of damage is caused by weevil grubs, or larvae, feeding in the partially matured nuts. Damaged mature nuts bleed little and do not drop prematurely; in fact a high percentage will not fall at harvest since the shucks do not open at maturity. The grubs feed on the kernels for several weeks. When fully grown, about three-fifths inch long, the creamy-white grubs with reddish-brown heads leave the nut through circular holes about one-eighth inch in diameter. These larvae enter the soil where they remain for 2 or 3 years before emerging as adults. Infested nuts are worthless since the larvae normally destroy the kernels, and the shucks often adhere to the shell. This damage is noticeable at harvest time. Practically the entire crop may be destroyed in seasons when large numbers of weevils are present. Few insects match or surpass it as a pest of pecan or hickory.

Control: The timing of weevil spray is determined by the appearance of the adults, usually during late summer, August-September. Growers not prepared to spray and those with dooryard trees can reduce weevil injury by placing sheets under trees and lightly jarring the limbs to shake weevils free. The weevils can then be collected and killed.

MITES

Several speices of mites attack pecan trees throughout the Pecan Belt. The most common and injurious mite is known only by its scientific name, Eotetranychus hicoriae (McGregor), but it is somethimes referred to as the pecan leaf-scorch mite. Heavy infestations of this mite cause serious foliage loss. The mite is pale green and barely visible to the naked eye. It feeds primarily on the undersides of the leaves, but occasionally may be found on the upper sides.

Affected leaflets show a slight discoloration between the veins near the midribs where the mites usually begin feeding. Later, the discoloration spreads outward, and the leaflets appear scorched. Severe scorch symptoms are dark-brown or liver-colored blotches that later develop into dead areas of irregular size and pattern. Severely injured leaflets turn brown and drop off. Infestation generally starts on the lower branches of pecan trees and spreads upward. Injury has been observed in June, but is usually more severe from late summer to frost. The mites develop rapidly in hot dry weather and produce numerous generations each year.

Control: Treatment for mites can be combined with that for aphids and with that for diseases since they are needed at or near the same time.

FALL WEBWORM

Fall webworms, the larvae of the moth Hyphantria cunea (Drury), feed in colonies and produce large dirty-white webs on the terminal branches of pecan trees in late summer and fall. These caterpillars hatch from a mass of greenish-white eggs deposited on a leaf by a single moth. They feed on both surfaces of the leaves and enlarge the web as they spread.

The fully grown caterpillars, about 1 inch long, are covered with long white and black hairs. They spin flimsy hairy cocoons beneath loose debris near the surface of the soil. The adult moths have a wingspan of about 1 inch, are usually white, and sometimes have a few black or brown spots on the forewings. Usually there are two broods a year, the second feeding late in the summer and in the fall. The insect overwinters as a pupa, and moths appear during the following year in April or May.

Control: Control is usually only necessary when the insects are numerous in a grove, but any chemical insecticides should be applied when the caterpillars are small. It may be practical to mechanically remove the webs of small populations from the trees before the caterpillars have left them and preferably before they have done much feeding.

WALNUT CATERPILLAR

Walnut caterpillars, the larvae of the moth Datana integerrima Grote & Robinson, feed in groups that often eat all the leaves on small pecan trees or on individual limbs of large trees; however, they do not form webs on the leaves. The immature larvae are reddish brown and have narrow cream-colored lines that extend the length of the body. The full-grown caterpillars are black, nearly 2 inches long, and thickly covered with long dirty-white or grayish hairs.

In southern regions the first generation appears in June and July, and the second generation in late August and September. The walnut caterpillar is found in pecan producing areas east of the 100th meridian; west Texas, Arizona, and New Mexico are currently free of this pest.

Control: Spray treatments similar to those recommended for the fall webworm will control this insect. Caterpillars clustered on the trunk or limbs of a tree may be destroyed by crushing or burning.

PINHOLE AND SHOTHOLE BORERS

Several similar insect species attack weak pecan trees. Some feed only on the bark and in the cambium region; others burrow deep into the heartwood. Occasionally they attack healthy trees, but they rarely cause serious damage since the larvae cannot subsist on wood with a good sap flow. Severe drought, mechanical damage, or cold injury often weaken trees for borer attack.

The so-called pinhole borers or scolytid ambrosia beetles, Xyleborus affinis Eichhoff, X. ferrugineus (Fab.), and X. saxeseni (Ratzeburg) which inhabit the trunks and stems of many hardwood trees in the southeastern United States, also damage pecan trees. These scolytid beetles infest all sizes of pecan trees ranging from 1-year-old nursery trees to 50-year-old trees in commercial plantings. The adults are small brown to reddish-brown elongate beetles with compact cylindrical bodies about one-tenth inch long. The beetles bore holes one-sixteenth to one-thirty-second inch in diameter in the pecan stem and lay their eggs in the sapwood. The entrance holes give the tree trunk or stem the appearance of having been hit by shot. As the beetles construct the galleries, they push the sawdust-like borings to the outside through the entrance hole. The white C-shaped grubs feed upon fungi growing in the brood cells constructed by the beetles. The associated fungi often give pecan wood a blueish-black stain.

Control: To control the borers, maintain healthy trees by good fertilization and watering practices, reduce sources of infestation, such as dead wood and prunings, and control winter injury by wrapping and planting the proper cultivars.

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PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key--out of the reach of children and animals--and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

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